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Combination of Biological Water Treatment and Ozonization in a Closed Sea-Water Recycling System

by

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1. Introduction

The trend to develop intensive warm water fish culture in temperate latitudes is based on a positive assessment of the possible use of "waste energy", particularly in the form of waste heat. However, even if waste heat, in the form of cooling water from different industrial processes (e.g. from power plants, refineries and the plastics industry) can be utilized, it must be noted that it a) is not always available in sufficient quantities; b) does not provide an adequate water quality for successful fish culture; c) where it is availabe in unlimited quantities (e.g. power plants) exhibits too low a temperature difference (Δ t = 7-8°C) with respect to the outside temperature in the winter months to enable the majority of the suitable species to grow well. Furthermore, the new version of the Abwasserabgaben-gesetz /Sewage Discharge Act/ requires that fish breeders discharge into receiving waters in the future limited quantities of effluent containing as low a level of pollution as possible or treat this water accordingly.

In order to become independent to a large extent of the water quality of waste-heat suppliers and of the site and to minimize the discharge of organically contaminated water into receiving waters, it is possible to use suitable recycling systems with the appropriate mechanical, biological and chemical treatment methods.

The reuse of water through recycling is not new. In particular, public aquaria in the Federal Republic of Germany have repeatedly used recycling technology, when necessary, to keep sensitive sea animals at sites far removed from the sea coast. These cases involved the exposition of only

a few animals in especially clear water. On the other hand, good growth and high densities with low susceptibility to disease are the critera for success in fish culture. Among the earlier works and the subsequent studies on the use of recycling in fish culture, the studies by Hirayama (1966), Meske (1971), Braun (1972), Broussard (1974), Meade (1973, 1974), Liao and Mayo (1972, 1974), Kausch (1976) and Nägel et al. (1976), in particular, should be mentioned: 2
they attempted to incorporate into fish culture various recycling treatment processes, like activated sludge, gravel bed filters and trickling filters, which were well-known aspects of the conventional treatment of effluent.

These studies concentrated primarily, as did many others, on the elimination of the nitrogen components ammonium and nitrite, which are known to be toxic, and usually assumed that a stable equilibrium can be brought about between the effluent produced by the fish stock and the efficiency of the biological treatment in breaking down this effluent. The frequently described "operatability" of the test installation often was based on criteria which were not interpreted uniformly. "Operatability" was certified, especially in the initial phase, if fish survived and grew in a "quasi"-closed recycling system. Subsequently, value was placed on good growth under increasing stock densities, without taking into account the production costs. In practice, however, experimental results are often extrapolated and applied linearly, and uncritically, to large commercial installations, and the resulting problems are generally underestimated.

For example, from approximately 1973 on, numerous recycling systems and other intensive fish-fattening installations have been built in the Federal

Republic and in other European countries. In the meantime, a large number of these installations have been shut down because they are inoperatable or are operating with high capital losses on account of their production output having been incorrectly estimated. There are many reasons for the strikingly poor development of this basically promising industry:

- The originally assumed equilibrium between the effluent load produced by the fish and the biological treatment in direct recycling for commercial production cannot be attained easily in large installations.
- With respect to the volume relationships between the fish rearing tanks and the treatment unit, there was a large discrepancy between the designs of the installations in large public aquaria, in research facilities and in commercial units. 3
- Our knowledge of the dynamics of biochemical processes in recycling systems and in intensive installations was too inadequate, and often still is today, to allow reliable process engineering instructions guaranteeing a satisfactory management of water quality to be drawn up for practical application.
- In addition, untrained investors have underestimated to a large extent the complexity of the processes involved. As well, the experts have failed to properly integrate the necessary disciplines in time. It is only since the end of the seventies, not least because of the research projects supported by the BMFT /Federal Ministry of Research and Technology/, that the required multi-disciplinary approach to the solution of the existing problems has been developed and supported. In the project we completed and in the preceding study, fluctuations

in the daily cycle of water quality, which had been largely ignored until our project was carried out, were described and presented experimentally for a few fish species, fish sizes and stocking densities, on the one hand, and, on the other hand, their effects on the efficiency of the water treatment system were demonstrated.

Results are available from numerous more recent studies with regard to individual processes. Special reference should be made to a few of the studeis which had a great influence on our project method: Burleson et al. (1975), Hampson (1976), Bullock and Stuckey (1977), Pettigrew et al. (1978), Hess (1979), Meade (1979), Berka et al. (1980), Liao (1980), Muir (1982). The two-volume work containing the contributions to the FAO/EIFAC/ICES Symposium on "Utilization of Heated Effluents in Flow-through and Recirculation Systems" held in Stavanger in 1980 is a comprehensive summary of our knowledge of recycling technology. The following publications, which originated in our institute, were taken into account in analyzing the problems associated with the research described in this project report: 4

Rosenthal (1974), Rosenthal and HInz (1975), Rosenthal and Sander (1975), Westernhagen and Rosenthal (1975), Sander and Rosenthal ((1975), Kuhlmann and Rosenthal (1976), Rosenthal and Westernhagen (1976), Otte et al. (1977), Rosenthal et al. (1977), Otte and Rosenthal (1978), Rosenthal et al. (1978, a, b), Rosenthal and Otte (1978), Otte and Rosenthal (1979), Rosenthal et al. (1979), Rosenthal (1980 a, b), Rosenthal et al. (1980), Rosenthal and Otte (1980).

2. Purposes of the Study and Methods

2.1 Working concept and purposes of the study

Previous studies dealt with the degradation efficiency and the water quality attainable in the treatment of fish effluents with biological filters, investigated the efficiency of a prior mechanical removal of solid matter and its effect on the efficiency of the biological treatment system, tested the effect of varying salinities on some degradation processes in trickling filters and studied the oxidation of fish effluents with ozone. They also dealt with the use of technical oxygen and its effect on the function of individual elements of the system. These studies show clearly that conventional recycling, in which the water circulates directly between the fish rearing and the treatment units, is not optimal insofar as the requirements of mechanical and biochemical treatment systems are concerned (Fig. 1a). The interaction between the system components is too great to ensure a stable, practical method of operation on a long-term basis, where the requirements and conditions for intensive fish culture vary. In order to optimize the operational efficiency of individual system components, new ways of combining the different treatment processes have to be tested (Fig. 1b - c). The concept pursued by us up to now of the "multiple-cycle system", in which all of the essential system components are operated in bypass (Fig. 1d), has proven itself to be the most suitable process to control water quality at present. The aim of this concept is to ensure the long-term regulation of the biological degradation process so that it can be controlled to a large extent and at the same time to shift the volumes taken up by individual system components in favour of the fish culture unit. It is precisely in respect to the volume-ratio of fish-rearing

tanks to treatment units in recycling systems that there is considerable discrepancy between the layouts of public aquaria and research facilities and those of commercial installations. This is illustrated with reference to a few examples in Table 1, and it underlines the problems, described in the introduction, of the use of recycling technology under practical conditions.

Therefore the project focused on the following objectives:

a) the problem of evening out the fluctuations in water quality throughout the daily cycle,

b) studies to optimize essential system components, like fish tanks, biological filters, ozonization and denitrification,

c) the application of the knowledge obtained up to now through planned study of and advising of commercial operations.

2.2 Test installations

Most of the studies were carried out in the recycling installations of the new building of the Zentrale of the Biologische Anstalt Helgoland. Further studies were conducted in practical operations (Auetal Fish Culture Facility, Rosenweiher Trout Farm, Kellinghusen). Whereas the Auetal facility is operated exclusively in flow-through, the Kellinghusen facility operates only partially with well water and recirculates a considerable amount of water through a settling pond and a neighbouring flooded gravel pit.

The layout of the recycling system used in the Zentrale of the Biologische Anstalt Helgoland is reproduced in Figure 2. There are three recycling systems in total, which have similar layouts in principle but which deviate in many

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Table 1: Some examples of the volumes taken up by the treatment and fish-rearing units in experimental and commercial fish culture recycling systems.

2) System-volumen (l)	1) Prozentualer Volumenanteil 3) Fischzucht-becken	4) Auf-bereitung	5) maximale Besatzmenge (kg)	6) Fisch/Wasser Verhältnis	7) Autor
8) Experimentelle Anlagen					
110	5.5	94.5	0.003	1:36.000	Rosenthal (1968)
647	7.7	92.3	6.5	1:100	Senckbusch (1976)
8.200	11	89	45.0	1:182	Otte et al. (1977)
1.200	37	63	1.5	1:800	Rosenthal (1970)
					Rosenthal & Fonds (1973)
7.800	15.4	84.6	24.0	1:325 - 1:50	Kausch (1976)
12.500	9.6	90.4	50.0	1.250 - 1:24	Kausch (1976)
59.600	10.9	89.1	300-1.500	1:200 - 1:40	Nägel et al. (1976)
2.000	10.0	90.0	26.0	1:77	Nägel et al. (1976)
9) Kommerzielle Anlagen (Daten aus der Praxis)					
50.000	70.4	29.6	?	?	Webori-System
150.000	60.0	40.0	1020.0	?	Webori-System
180.000	66.0	34.0	10) kurzfristig ?	?	Webori-System
57.000	21.1	78.9	?	?	Stählermatik

Translation key to Table 1:

1) Percentage volume; 2) volume of the system (l); 3) fish rearing tank; 4) treatment; 5) maximum stocking (kg); 6) fish/water ratio; 7) author; 8) experimental installations; 9) commercial installations (data from practical operations); 10) short-term

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details from the layout presented. According to this layout, the system is made up of several sub-recycling systems to which individual functions are allocated: sedimentation of contaminants (A, B); biological treatment (C); aeration (D); temperature regulation (E, F); chemical water treatment (ozonization) (G, H).

The water flow in all sub-recycling systems is maintained by only one pump (I). There is a reserve pump (J) which comes into action automatically should the first pump malfunction, the reversal of the feed current being regulated by flap-valves. Some of the pumped water is fed through a trickling filter (biological treatment) (C), some stored in the overhead tank (K). The sub-flows are controlled by flow meters (L) and can be changed. The water flows in a free fall from the overhead tank to the consumers (aquaria) (N). More water is always pumped into the overhead tank than required by the consumers. The excess flows back into the sump (D). The sump also serves as a secondary aeration tank. As well, the water level in it is regulated by means of a capacitive level valve: in the case of losses from leakages and from spray water, of the filling of new aquaria to be connected and of sampling for water analysis, the motor valve (M) of the equalizing tank (O) opens and fills the sump up to the set height of the level valve (S). When aquaria are emptied into the system, the water level in the sump rises:

excess water is pumped into the equalizing tank by a pump (P), until the tank is full. This procedure is intended to minimize water consumption in view of the limited sea-water stored in the storage tank and, at the same time, to simplify the operation of the installation where the consumers' water needs vary. Evapouration losses are made up through a connection to the building's drinking water system (Q).

The water treated in the trickling filter (C) flows through a settling 8
tank (B) to the secondary aeration (sump). Excess sludge is deposited in the settling tank, from which it is removed at regular intervals (time clock) and is filtered out in the sludge collector (R) through a fine mesh plankton gauze. The filtered water is pumped off periodically (depending on the water level in the sludge collector) and returned to the central cylinder of the settling tank. The recycled water is subjected to the settling process once again to ensure that any contaminant particles passing through the plankton sieve are removed from the system.

The chemical water treatment (ozonization) (G, H) is also carried out in a sub-flow of the water pumped by the main pump (I). It is operated discontinuously and is connected to the system solely by hoses. The treatment of the water takes place in a reaction tower (H) in which air containing ozone is fed into the lower part by means of a high-speed rotating disc. The water is treated with ozone on the counter-current principle, the resulting contaminant-containing foam being driven out through a collecting funnel mounted on top. The foam is constantly washed down (in the sludge box (T) by spraying). The water flowing out of the reaction tower flows to the outflow trough.

The temperature is regulated through a bypass loop (E and F) as well; a small sub-flow is cooled (E) or heated (F), as the case may be, and the temperature regulation is controlled by means of thermofeelers (U, V) in the mixed water after a certain flow path. This method allows for the temperature to be set very accurately, without high demands being made on the reaction tolerances of the by-pass regulators.

The water flows directly from the overhead tank to the rearing area. The used water flowing out of the aquaria flows through V-shaped discharge troughs or slightly sloped pipes to the treatment unit. In this unit, most of the solid material (feces and feed residue) is removed first in a settling tank (A). The water is then fed into the secondary aeration tank (D) where it mixes with the water discharged from the biological treatment. In this way, large fluctuations in the effluent load are reduced through dilution, which helps to stabilize the degradation efficiency of the trickling filter. From this point, the mixed water flows to the pumps again, and the cycle described at the beginning starts again. 9

The total volume of the system is about 10 to 14 m^3, depending on the number of aquaria and fish tanks connected together. A water volume of between 4 and 6 m^3 is available every hour to supply the rearing facilities. The installation is designed for low loading values.

2.3 Water chemical analysis

The following water chemical parameters, among others, were analyzed in order to assess the individual system components: NH_4^+, NO_2^-, NO_3^-, BOD_5, COD, TOC, pH-value, O_2-content, salinity, temperature. The amount of free NH_3 was calculated, taking into account temperature, pH-value and salinity.

Samples were taken over long periods, occasionally also at hourly or half-hourly intervals over a full daily cycle or over an 8 to 10 hour period after feeding, in order to record load peaks. Water samples taken on weekdays for analysis were routinely taken before the first feeding in order to study long-term trends in degradation efficiency. Samples were always taken in the inflow and outflow of the individual system components.

3. Biological Water Treatment

To assess the problem of the extent to which the water quality in a fish culture recycling system is adequate for the optimal growth of a healthy fish stock, the course of the daily cycle of the degradation curve of the bio-filter must be known. Only when this is known, can measures to improve water quality be developed. The decisive factor for the growth and the feed utilization of the fish stock is how long maximum load peaks caused by products of metabolic exretion occur. Based on our experience, fixed-bed filters are very well suited for recycling systems in order to treat fish effluent, assuming the organic suspended solid materials, usually feces and feed residue, can be removed effectively and promptly from the system.

In addition to the degradation of organic material by heterotrophic bacteria, the nitrification of the nitrogen components ammonium and nitrite is important. The end product of nitrification, the nitrate, is generally regarded as a largely harmless dissolved substance which is tolerated by the majority of the fish over a wide concentration range (Westin, 1974; Meade, 1976). It is known, however, that a considerable amount of the nitrate-nitrogen can be eliminated through anaerobic denitrification (Wuhrmann, 1966; Klotter,

1969; Shan and Coulman, 1978), in which case the known processes can also be operated more or less successfully with fish effluents. However they should preferably be operated in bypass (Otte and Rosenthal, 1979; Hilge, 1982). In order to prevent the above-mentioned short-term exposure of fish to increased concentrations of metabolic excretion products, the efficiency of the biological treatment must be adapted to the expected daily fluctuations in load. Therefore we must be just as capable of assessing the degradation efficiency in the start-up phase of the system as we are of assessing it with different stocking densities and with different materials. In addition, how the efficiency of a given system layout is impaired by different, varying environmental factors (e.g. temperature, pH-value, total ammonium, nitrite, BOD load, hydraulic load and other components) must be tested.

The studies carried out with regard to these problems are described below. 11

3.1 Run-in phase of a trickling filter

Only a few quantifiable studies are available on the behaviour of degradation efficiency and of loading in the run-in phase of newly installed treatment systems. The technical literature usually contains only rough figures on the duration of the run-in phase of trickling filters and other biological treatment processes; however, only rarely are the limiting conditions described. Because the loading in the new systems installed in the Zentrale of the Biologische Anstalt Helgoland is considerably lower, on account of their special testing purpose, than in all comparable systems tested up to now, it was interesting to study the duration of the run-in phase under these conditions

as well as to test how degradation efficiency behaves during this phase in different horizons of the trickling filter, in particular in the upper levels using the new BIO-NET material as substrate.

Figures 3 and 4 show the inflow values (position 1) and outflow values (position 5) for ammonium and nitrite as well as the values for three sampling points 50 cm, 95 cm and 115 cm (positions 2-4) belowthe surface. The results show that the run-in phase lasted less than a month and the initial values never rose significantly above 0.4 mg/l total ammonium. However, it must be emphasized that the system was operated a few weeks before without any fish stock (technical operating test period). The second stage of nitrification did not require much longer to reach acceptable degradation values but, with peak values of around 0.5 to 1.0 mg NO_2^-/l, was relatively high during the first two weeks after the system was stocked. During this period, no significant concentration gradients could be observed in the different horizons of the trickling filter. This indicates that degradation efficiency during this period was very low.

The speed with which the first nitrification phase took effect is 12
attributable not least, to the low fish stock ($<$ 20 kg) and the low BOD load. It must be pointed out, however, that every minor change in loading during the following 6 months resulted in definite fluctuations in efficiency, and it was only subsequently that the trickling filter was stabilized to such an extent that large relative fluctuations in the concentrations of nitrogen components were controlled.

3.2 Long-term stabilization of water values in the recycling systems

After the recycling systems had been run in, the water quality was observed continuously for a period of more than 450 days, based on samples taken in the morning before the first feeding. In addition to the nitrogen components, other quality factors, such as salinity, pH-value, O_2-content, BOD, and occasionally TOC (total organic carbon), were analyzed. This section of the report deals only with the nitrogen values. The results in the three recycling systems, which were stocked differently and which were operated at different temperatures and salinities (Table 2), showed the following trends:

Ammonium: In recycling system 1, the concentrations rose slightly above 0.1 mg/l in only three samples. Systems 2 and 3 showed a definite increase in the values during the run-in phase after they had been stocked (Fig. 5; run-in phase = day 1-50). Subsequently, the values in all systems are far below 0.1 mg/l as a rule. The values in system 2, which was stocked with sea-urchins, beach crabs and starfish, fluctuated around the lower detectability limit.

Nitrite: Following the run-in phase, the nitrite concentrations exhibit greater fluctuations than the ammonium values, with the exception of system 2, although in total they are already at a higher concentration level. In system 1, they reach values around 0.4 mg/l twice during the observation period and fluctuate over long periods between 0.05 and 0.3 mg/l. It was only in the last months that a stable course below 0.1 mg/l was attained. 13

In system 2, the nitrite values also remained in the vicinity of the lower detectability limit (based on the routine method of analysis).

In system 3, the nitrite values fluctuated less than in system 1 after the run-in phase, despite the higher stocking (Fig. 6). Nitrate: In system 1, the nitrate content increased slowly but constantly during the observation period, reaching its maximum at 150 mg/l (Fig. 7). System 2 showed a rapid rise in nitrate content with a maximum of about 160 mg/l at the end of the run-in period and, subsequently, relatively stable values around 100 mg/l.

System 3 showed a constant rise of the nitrate curve to about 200 mg/l (after about 200 days) in accordance with the higher stocking. The reduction in the nitrate content after this date is attributable to the starting-up of a denitrification stage. Systems 1 and 2 are still being operated at present without denitrification units.

Table 2: Operating data for the three recycling systems containing different stocks

1) Kreislauf	2) Salzgehalt °/oo	3) Temperatur °C	4) Volumen m^3
1	30 - 33	10 - 15	12.0
2	15 - 20	15 - 20	10.0
3	20 - 30	20 - 25	12.0

Translation key to Table 2:

1) system; 2) salinity; 3) temperature; 4) volume

3.3 Comparison of the efficiencies of different trickling filter substrates

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The structure of the trickling filter substrate used determines in part the quantitative and in part also the qualitative compensation of the bacteria adhering to it. In order to minimize the interspecific competition of the heterotrophic and nitrifying bacteria and to separate them to a great extent spatially among the preferred substrates, the suitability of two different trickling filter substrates was tested in parallel operated units. The comparison test was carried out under otherwise comparable operating conditions and dealt with Hydropack foil (Uhde-Dortmund Ltd.; active surface 200 m^2/m^3) and BIO-NET material (Norddeutsche Seekabelwerke; 260 m^2/m^3 active surface).

The test results show that with both materials the oxidation efficiency for ammonium decreases rapidly as the input concentration increases. It was constantly below 60% with input concentrations greater than 1.0 mg/l total ammonium. With nitration, the oxidation curve for the Hydropack foil is considerably flatter than for the BIO-NET material, reaching its maximum at inflow concentrations between 0.4 and 0.7 mg NO_2^-/l. Then it decreases continuously, however never reaching a degradation efficiency as high as that of BIO-NET material.

The degradation efficiencies of both filter materials can be compared using the calculated regression straight lines between initial concentrations in the trickling filter inflow and degradation efficiencies. According to this comparison, ammonium oxidation appears to be 20% better on average when the BIO-NET substrate is used. However if the substrate surface available per

volume percentage is taken into account, it is evident that, mathematically, the BIO-NET substrate has about 23% more surface for bacteria to adhere to than the Hydropack material. Therefore the surface-related degradation efficiency hardly differs from the volume-related efficiency data. This becomes obvious if Figures 8 and 9, in which both reference values were considered, are compared.

3.4 Daily cycle of the degradation efficiencies of different bio-filters in high and low-rate systems

The efficiency of biological filters is influenced by the loading level and by the daily occurring fluctuations in the effluent load. Biotechnical methods which stabilize the efficiency of a biofilter can only be developed if a) the reaction of a filter to loading fluctuations is known and b) the expected frequency and amplitude of the fluctuations for individual effluent compenents can be predicted at a given stocking density. We investigated, therefore, how the water quality values for ammonium, nitrite, pH-value and BOD change as loading increases and how these values influence the degradation efficiency of bio-filters. The recycling systems were operated at temperatures of about 25°C and at salinities of 16 $^{0}/_{00}$ and 22 $^{0}/_{00}$ for these tests. The fish stock was approximately 900 kg and 30 kg; the total volumes of both systems was about 14 m³.

Figure 10 reproduces a typical example of the numerous tests on the daily fluctuations of water quality in a high-rate system. In each case, the curves are based on the inflow and outflow values of the trickling filter (volume 4.42 m³ ; surface 260 m²/m³ , hydraulic surface load 4.5 m³/m²/h).

The amplitude of the diurnal fluctuations in the high-rate system was particularly high for the ammonium and nitrite values and relatively low for the pH and oxygen values. The individual curves reached their maximums at different times of the day. Whereas the BOD value was highest immediately after feeding, the ammonium curve reached its maximum about 9 hours later. The peak values for nitrite were observed approximately 13 hours after feeding. The differential curve between inflow and outflow values for oxygen shows definite consumption during the maximal oxidation phase of the first nitrification stage, whereas in the evening and night hours the chimney effect of 16
the trickling filter is sufficient to even produce a small oxygen enrichment (Fig. 10). The carbon degradation (BOD reduction) constantly produced relatively high degradation values. Following the sudden loading resulting from feeding (the entire daily ration was given in one feeding in the morning), it reacted within only 2 hours with an above-average increase in the percentage degradation efficiency (about 60%). Approximately 6 hours later, the curve had decreased to a minimum and stabilized at degradation values of about 40% in the further course of the day. The BOD attained maximum values of around 20 mg/l in the inflow. It was only when both the BOD degradation and ammonium oxidation had exceeded their maximums that the efficiency of the nitrite oxidation reached high values. Consequently, this shows that the BOD load in recycling systems has to be kept as low as possible in order not to reduce the efficiency of the nitrification.

In contrast to the above, low-rate systems (inflow values for ammonium increased by a factor of 30 in high-rate systems; for nitrite, a factor of 10 is valid) show a smaller fluctuation in the outflow values and a constantly

higher oxidation efficiency, even during feeding phases. The interruption in nitration is evident only immediately after the first feeding, and the second stage of the nitrification recovers much faster than in the high-rate system (Fig. 11).

General differences in the data on the efficiencies of various low-rate bio-filters (trickling filter - Fig. 11; immersed drum reactor - Fig. 12) indicate that the immersed drum reactor reacts more quickly to loading fluctuations than the trickling filter but in doing so remains set at an overall lower efficiency level. On average, the trickling filter degrades 60% of the ammonium, whereas the efficiency of the immersed drum reactor levels off at between 30% and 40% outside of peak loading periods.

The differences in nitrite degradation in low and high-rate systems are also presented in Figures 10 to 12, only the inflow and outflow values 17
being used as the evaluation basis. If it is assumed that the second stage of nitrification must also overcome the converted ammonium, the actual nitration efficiency is substantially higher. If this conversion is included in the total nitrite oxidation balance, the curves presented in Figure 13 result for all three bio-filters. Both the low and the high-rate trickling filters exhibit, after an initial fall in the values, a comparable nitrite conversion over the course of the day, in which case the efficiency of the low-rate trickling filter tends to fall off frequently and for short periods. In both cases, as expected, the percentage of nitrite degraded is considerably higher. On the other hand, the immersed drum reactor does not produce these differences in efficiency but suffers no significant decrease in

degradation values after the first feeding. This is important for the stabilization of the outflow values in a system with high fluctuations throughout the day.

The differences between the pH-value fluctuations in the two bio-filters tested were striking. Whereas in the trickling filters only a small increase in pH was observed (smaller than 0.1 units in all cases), it was greater than 0.2 units in the immersed drum reactor. Although, in general, it can be assumed that a well functioning nitrification constantly consumes alkalinity and, thus, actually would have to reduce the pH-value, the reverse behaviour observed in this case can be interpreted on the basis of the technology of the system. The intensive aeration in both systems results in a definite "stripping" effect, which drives out a considerable portion of the CO_2 concentrated through the respiration of the fish and the activity of the bio-filters. Since the aeration in the immersed drum reactor takes place directly in the medium and a considerably higher quantity of air takes part in the gas exchange per treated volume unit than in the trickling filter, the CO_2-expulsion is greater and, in the last analysis, results in a greater increase in the pH-value than in the trickling filter.

3.5 Integration of a rotating drum reactor in the fish culture recycling system 18

For several years, the manufacturers of systems have been offering filter systems which have been modified many times and which are supposed to be applicable in the treatment of effluents from fish culture systems in particular and which, above all, can be considered for use in recycling systems.

Various types of rotating drum reactors have been discussed repeatedly. Unfortunately, up to now usable data on their efficiency which also takes into account the dynamics of pollution fluctuations was available solely for high-rate systems but not for low-rate fish effluents. As already stated, such data is essential, however, for the working up of dimensioning criteria.

In the course of the project, as a result of the collaboration undertaken with the University of Hamburg (Prof. Sekulov) and the Norddeutsche Seekabelwerke /North German Sea Cable Works/ (Dr. Wittek), a rotating drum reactor with a new type of material was integrated into the test system and its efficiency tested both over longer periods as well as in short test phases. In particular, we tested how the degradation efficiency changes for the nitrogen components if the loading varies greatly for a short period. This was important insofar as the original application of the newly developed rotating drum reactor was to be the treatment of relatively weakly polluted drinking water and was primarily intended to support nitrification. Based on the existing design criteria, its use in the water treatment unit of a fish culture recycling system appeared definitely worth testing.

3.5.1 Design of the drum filter

The fixed bed of the drum filter consists of a completely submerged rotating plastic unit with a porous mesh structure. The substrate to be treated and the air required are fed to the rotor axially and forwarded by the rotation to the reaction surfaces covered with heterotrophic bacteria and nitrifiers. In contrast to the known drum reactors, in this process the 19
the flow of the medium to be treated is continuous and radially directed

outward, making it possible to control the distribution to a large extent by means of the rotor speed and the regulated inflow and, as a result, making it possible to control the hydraulic load in the entire system better. The operating data adhered to in the test are: specific surface = 380 m^2/m^3 ; volume of the fixed bed = 0.252 m^3 ; fixed bed surface = 29 m^2 ; hydraulic load = 2.88 (at 30 l/min.) to 5.72 (at 60 l/min.) m^3/m^3 x d.

3.5.2 Run-in phase of the reactor

The rotating drum reactor, which had first been operated at the University of Hamburg, was conditioned by Prof. Sekulov's associates to a high degradation efficieny of the nitrifiers and after a stabilization of several weeks, gradually adapted to the salinity prevailing in our recycling system. The reactor prepared in this manner was then transported in an active state to the Zentrale of the Biologische Anstalt and integrated into the system.

Contrary to our expectations the adaptation phase following the reactor's connection to the fish culture recycling system was very unstable and took extremely long. The bacterial species adhering to the filter material seemed to adjust only extremely slowly to a new equilibrium with the bacterial populations present in the recycling water. This is made especially clear by the great fluctuations in degradation, which stopped completely at times.

The adaptation phase took several months in total. During this period, considerable differences appeared in the degradation efficiency of the first and second nitrification stages as well, so that at times large amounts of nitrite were found in the reactor outflow, which underlines the dominance of the nitrosomonas populations.

3.5.3 Efficiency of nitrification during stable operating phases 20

At times, the degradation efficiency of the rotating drum reactor was observed at three different flow-through rates (30, 45 and 60 l/h). These flow-through amounts corresponded to a theoretical retention time of 8.4, 5.6 and 4.2 hours respectively, not taking into account the dilution effect within the system. This can be disregarded insofar as the medium is fed in from the central rotating axis and, thus, the retention time in the drum zone is determined by the flow rate of the medium outward from the feed point and does not depend on the total volume of water in the container in which the immersed drum rotates.

Figure 14 shows the course of the curves for the concentration of total ammonium in the inflow and outflow of the reactor following the morning feeding of the fish i the rearing facilities. The curves each represent two comparable test series with a flow-through rate of 30 and 60 l per hour respectively.

3.5.4 Reaction of the degradation efficiency to fluctuations in load

The inflow concentrations for ammonium and nitrite fluctuated considerably in the system because of the single feeding of the full daily ration. Prior to the feeding, they lay between 0.01 and 0.05 mg NH_4^+/l in the inflow, increasing within 2.5 to 4 hours to their maximum of between 0.05 and 0.09 mg NH_4^+/l respectively. If the hydraulic feed was held constant, the efficiency of the ammonium oxidation decreased considerably during the increase in concentration (at times to zero); ammonium was even produced on one test day (Fig. 14). The importance of short-term absolute fluctuations in efficiency

is not evident when the degradation efficiency is related to the initial concentration. This shows that in the lower concentrations the higher flow-through rate produces approximately the same degradation efficiency as the low one. However it is only in two observation series that the rise in ammonium oxidation, as the inflow concentration increases, is clearly higher than in the series with a 30 l/h flow-through. 21

In order to stabilize the outflow values and, thus, to hold the efficiency of the oxidation of the total amount of nitrogen constant to a great degree, the hydraulic feed was cut in half for 6 hours in each case during the phase in which inflow values increased. As Figure 14 shows, the outflow values constantly remained at the same low level during these tests and always lay between 0.04 and 0.02 mg NH_4^+/l following feeding times. At the same time, the relative degradation efficiency was stabilized considerably and only seldom dropped below 50%.

A comparable picture results for the degradation of nitrite in general, although the concentration range was about one power of ten higher (Fig. 15). The comparison of the temporal course of the degradation efficiency for nitrite as a function of the changes in the inflow concentration following feeding, where the hydraulic load is constant, is illuminating.

Whereas on days without feeding there is almost a linear relationship between inflow concentration and total nitrite oxidized per time unit (Fig. 16; dark points), oxidation increases more quickly at first following feeding, as the initial concentration increases, then falls substantially after the maximum is reached, without the inflow values falling in the following hours (Fig. 16; open points).

This trend becomes clearer if the nitrite oxidized per time unit is related to the outflow concentrations (Fig. 17). Following feeding, the nitrite oxidized increases quickly as the concentration increases slightly but falls off considerably well before the concentration maximum is reached. This may be related to the efficiency of the nitration, which starts again after an initial inhibition, but is also influenced by the nitrite produced by the first nitrification stage. Therefore, the adaptation of the hydraulic load to the substrate availability appears to be a suitable means to stabi- 22
lize the nitrification of biological filters insofar as the outflow values can be held at a relatively constant level.

4. Anaerobic Denitrification Stage

Tests were carried out repeatedly regarding the inclusion of a denitrification stage. Methanol was used as a source of carbon. Earlier test series had repeatedly shown that the course of the curves for the relative nitrate and nitrite degradation (difference between inflow and outflow values of the denitrification stage) indicates incomplete degradation at times, in addition to periods of satisfactory stability in nitrate reduction. Thus over long periods, short unstable phases occur which sometimes result in the complete breakdown of the nitrate reduction. An example of such a breakdown is given in Figure 18, which covers an operating period of more than 8 months. Figure 18 shows clearly that every time the system breaks down considerable quantities of nitrite are released which may represent several times the concentration toxic to the fish. Since merely a small portion of the total volume of the recycling system flows through the denitrification unit, the actual outflow concentration is quickly diluted with the remaining volume

of the system but definitely contributes to the rise of the nitrite concentration level in the system as a whole. Consequently, the concentrations occurring are to be regarded as dangerous for long-term exposure of the organisms. It must be mentioned that in this test, the inflow water for the denitrification unit was taken from the settling tank, which operates behind the trickling filter in the system, and thus receives a minor amount of carbon from the fish effluent.

The instable denitrification phases described were not indicated by any unusual changes in the water chemical parameters studied up to now.

The pH-value of the culture water increases clearly as the water passes through the denitrification stage, which is probably due to the recovery of alkalinity. It is assumed that the occasional uncontrolled collapse of the denitrification stage is attributable to, among other things, a sub-critical availability of the required carbon source, because the organic load is subject to considerable diurnal fluctuations. 23

As part of this project, specific test series were carried out in a small denitrification unit (volume 110 l). This unit was integrated into the recycling system of the Zentrale (Biologische Anstalt Helgoland) described above, the effluent from the fish tanks being fed directly into the inflow (flow-through 0.5 l/min.).

In contrast to the previous denitrification tests, this unit was operated with a filling matter substrate (BIO-NET material, loose packing). The reduction efficiency fluctuated considerably in the initial phase, which is attributable in part to the slightly increased oxygen values (occasionally

about and greater than 0.5 mg0_2/1) and to fluctuations in the inflow volume. After about 100 days, however, a relatively constant level of nitrate reduction was attained (Fig. 19), which only rarely resulted in slightly higher nitrite values in the denitrification stage outflow. At times, the nitrite content was even smaller than in the inflow. The relatively stable reduction in the second test phase (100 - 250 days) indicates that the direct inflow of effluents from the fish tanks may have contributed to this stabilization. The effluents represent a more available carbon source than those taken from the settling tanks after the bio-filter, as described in the first test.

In the initial phase, the brief, high nitrite peak values of maximum 30 mg/l indicate an incomplete nitrate reduction. What was striking was that over the course of the daily cycle, the nitrite concentrations frequently increased more greatly than in the inflow. The denitrification stage affected the pH-value of the entire system considerably. Whereas the pH-value sank 24
constantly before the installation of the anaerobic stage and during the instable operating phase (about 100 days), it then increased rapidly and for a long period could be held at values between 7.9 and 8.2 (Fig. 20). In recycling system 1, a minor pH-value decrease from 8.2 to 7.9 was observed, which levelled off at a long-term value of 8.0. In recycling systems 1 and 2, which are operated without a denitrification stage, the pH-value decreases can be attributed only partly to an occasional water exchange. Rather, it is to be assumed that minor denitrification processes occur within the system which compensate to a large degree the nitrate concentration rate in accordance with the low fish stock.

In the last half of the second year of the project, 4 more test units of about 300 l volume (200 l water, 110 l filling material) were put into parallel operation in order to carry out optimization tests on them. The tests dealt with the question of the stratification of the reduction in stagnant and moving (agitated) systems with and without filter substrate. The orientation test series conducted in the remaining project period indicate that the nitrate reduction occurs more quickly in all stages of heavily agitated systems and reacts with less instability to concentration variations in the inflow. The substrate structure played a not unimportant role in this process. The filter substrates used were 5/8" and 1.0" BIO-NET (Norddeutsche Seekabelwerke). At the beginning, the material with the smaller diameter produced considerably better reduction values. This decreased clearly as the growth increased. Therefore, the large volume BIO-NET substrate proved to be distinctly better in long-term operation.

5. Chemical Treatment of Water with Ozone

As part of this project, the studies conducted in previous years on the effect of bypass ozonization on the recycling water of fish culture systems were intensified using a new contact system design. The oxidation 25
efficiency of the new foam tower was ascertained under different operating conditions in the course of this intensification.

5.1 Layout of the contact tower

The layout of the new contact tower is reproduced in Figure 21. In the cylindrical reaction space (dimensions: 49 cm in diameter, 192 cm in height, water volume: 362 l), fine bubbles of ozone-containing air are

distributed close to the bottom via a rapidly rotating disc (2400 rpm), while the water to be treated is fed into the upper part tangentially. The foam produced in this type of flotation process results from the counter-current principle. Particularly important for continuous foam removal is the design of the tapering connecting cone between the skimming tower and foam collector pipe. The foam is washed down in the upper part of the foam collector. With the given construction features, the dimensions of the cone play a role in determining whether large percentages of instable foam bubbles collapse prior to their removal, making numercus accumulated substances soluble again (or rather re-introducing them).

5.2 Test method

All tests were carried out in an internal recycling system having a total volume of 610 l. The system was emptied after every test and filled with fresh sea-water to which various substances (ammonium chloride, sodium nitrite and peptone) were added in accordance with the desired initial concentrations for ammonium, nitrite and BOD. The salinity varied between 11.5 $^{0}/_{00}$ and 15.4 $^{0}/_{00}$ S in the individual tests. The pH-values usually lay between 7.7 and 8.5. The ozone concentrations used in the tests were not determined directly but calculated on the basis of the performance data for different operating conditions (e.g. air flow-through, energy consumption) 26
supplied by the manufacturer. Whereas in the first test series the reduction of ammonium, nitrite and BOD (biological oxygen demand) was tested separately at a flow-through of 0.5 m^3/h, in the second series the reduction was studied at a higher rate of flow through the skimming tower (1.0 m^3/h).

The amounts of ozone calculated to have been used in all tests (more exactly = total amount of oxidizing radicals) are listed for both water flow-through rates in Table 3.

Table 3: Tests on oxidation efficiency in a skimming tower operated on the counter-current principle at different flow-through rates and ozone concentrations.

1)	2)	
rechnerisch applizierte Ozonmenge (O_3/h)	Ozonkonzentration (mg/l) bei Wasserdurchflußraten von 0.5 m^3/h	1.0 m^3/h
10.5	21	10.5
6.5	13	6.5
2.0	4	2.0

Translation key to Table 3:

1) ozone calculated to have been used; 2) ozone concentration (mg/l) at water flow-through rates of

5.3 Oxidation efficiency of individual effluent components

Figures 22a, b and d show the oxidation efficiencies of the skimming tower for ammonium, nitrite and BOD (peptone) at a flow-through rate of 0.5 m^3/h. In all these tests, the respective effluents mentioned were studied separately. Figure 22c reproduces the reduction curves for ammonium and nitrite when both of these substances occur simultaneously in the medium treated.

Based on these curves, the oxidation time required under the test conditions given is a function of the ozone concentration used. In the case of ammonium, the time required for complete oxidation varies between 120 and 270 minutes. Nitrite is oxidized much more quickly (between 100 and 110 minutes treatment time), in which case the initial concentration for nitrite and the amount of ozone used play hardly any role for the end point of the oxidation. The BOD content of the water was almost completely reduced in one hour within the concentration range studied (3 - 4 mg BOD_5/l). 27

The tests using double the flow-through rates (1.0 m^3/h) produced similar reduction curves for the separate oxidation of ammonium, nitrite and BOD, which generally require much less time for complete oxidation than is the case in tests with double the retention time (Fig. 23). However these curves do not always exhibit the same trends. Whereas the oxidation time for ammonium is reduced by 25%, it is almost cut in half for nitrite. However, the retention time was too short to completely degrade the BOD, at least for the lowest ozone concentration.

5.4 Oxidation efficiency in the combined treatment of effluent components

In those tests in which ammonium and nitrite were present in the water at the same time, the oxidation of ammonium was slightly delayed initially at both flow-through rates. It was only after most of the nitrite had been oxidized that the reduction of ammonium proceeded with approximately the same speed as before.

Where all three of the effluent components studied were present jointly in the medium to be treated, the oxidation of ammonium started later

with all of the ozone quantities and flow-through rates used (Fig. 24). It also took, depending upon the ozone concentration, between 10 and 30 minutes longer to complete than was required with separate treatment.

Where the higher flow-through rate is used, a minor increase in ammonium concentration can even be observed at the beginning of the treatment, 28 regardless of the ozone dosage. Following a treatment period of about 30 to 60 minutes, however, the oxidation process begins to operate with normal efficiency (Fig. 25), at which point most of the nitrite and BOD have generally been reduced.

It can be concluded from these tests that ozone-assisted ammonium reduction is inefficient. However the process is suitable for the rapid oxidation of nitrite and in the case of a low BOD loading, for its rapid reduction as well.

At a total volume of 610 l, the tests produced the performance data listed in Table 4 with regard to the integration of the ozonization in the existing recycling systems (12 m^3 volume).

Table 4: Time required for the oxidation of ammonium and nitrite at maximum initial concentrations of 1.0 mg NH_4^+/l and 0.2 mg NO_2^-/l in the culture medium (total volume of the system 12 m^3) with two flow-through rates. The reduction efficiency is valid for effluents with an initial BOD content of 4.0 mg/l (salinity = 11.5 - 15.4 $^0/_{00}$; temperature = 19 - 25°C; pH = 7.7 - 8.5). The numbers in brackets give the time required for complete reduction; the effect of dilution of the treated medium with the recycling water is not taken into account if the ozonization unit is operated in bypass.

O_3 g/h	50 o/o - NH_4^+ - Abbau[1] z)(Std) 0.5 m^3/h	1.0 m^3/h	50 o/o - NO_2^- - Abbau[1] z)(Std) 0.5 m^3/h	1.0 m^3/h
2.0	25.0	17.0	5.0	4.0
	(?)	(26.0)	(15.0)	(11.0)
6.5	8.0	10.0	3.0	3.0
	(14.0)	(15.0)	(12.0)	(7.0)
10.5	7.0	7.0	3.0	3.0
	(11.0)	(11.0)	(11.0)	(7.0)

Translation key to Table 4:

1) reduction; 2) hour

6. System Component: Fish Culture as Influencing Variable for the Functioning of Water Treatment 29

Knowledge of the water exchange and of the relevant mixing ratios with the inflow is very important for the maintenance of good water qualities in holding systems like aquaria and large fish tanks. It is especially in large circular tanks that the distribution of the inflow water becomes more difficult as the stocking density increases. This results in a further increase in the fluctuations in concentrations of metabolic excretion products, which has a negative effect on the treatment, particularly in the recycling operation. As part of the project, therefore, basic data was collected especially on water exchange in troughs and circular tanks both in experimental systems as well as in commercial fish culture operations.

6.1 Observations in test facilities

The extent of diurnal fluctuations in various water quality values was described in the studies carried out under the preceding project (MFE 0503/8). Figure 26 contains an example of the pH-curves and nitrogen values in the tank inflow and outflow when the stocking density is approximately 1 : 11 (Tilapia biomass 32.0 kg, average weight about 52.0 g, tank volume 360 l, water inflow 11 - 12 l/min.). According to Figure 26, the maximum values for the ammonium concentration rose from 75% to more than 200% of the initial morning values for a short time after the third feeding. Obvious daily cycles are evident for nitrite and pH-value. A striking finding was, for example, that the curves for oxygen consumption in parallel operating tanks (replicas) deviated substantially from one another, although all controlled test conditions were largely identical (Fig. 27).

This deviation in the oxygen contents of more than 30% at times was caused essentially by the different swimming activity of the test animals, which occurred as a result of the disturbance experienced by the animals - which fluctuated greatly - during observation, sampling and maintenance of the system. These tests show clearly that the operation of the system and the associated behavioural reactions on the part of the animals exercises great influence on the course of water quality curves.

The extent of the fluctuations in metabolic activity and, thus, the varying concentration of metabolic products during the day also depends on the age of the fish however, as the example in Figure 28 shows.

In further tests, trout were exposed to different concentrations of metabolic excretion products in seven sequential holding sections in a flow

channel. As it passed through the holding sections, the water picked up the excretion products from the preceding section and lost oxygen correspondingly. Each section was stocked with approximately the same quantity of fish so that from section to section the loading corresponded to the relevant preceding total stock. Consequently, the effects of increasing stocking density on water quality were duplicated, without the actual stocking density in the individual sections being increased at the same time and the social and desnity-related stress in the sections being changed.

Figures 29 and 30 show the mean daily concentration of ammonium and the pollution peaks occurring in the course of the day. According to these Figures, these values are, based on the total ammonium loading, about twice as high as the average values ascertained from the diurnal observations. In some cases, nitrification already began at the end of the flow channel, preventing the further increase in ammonium concentration that had been expected from the calculations. Under the given test conditions, the growth of the individual fish was definitely reduced only in the three highest loading levels (Table 5). The losses were also greatest in them, which can be seen from the clear reduction in the biomass. The extent to which lower loading levels may have resulted in damage will have to wait for the histological examination of gills and organs. 31

Table 5: Tests on the graduated exposure of trout to metabolic excretion products from fish rearing. Growth data in the exposure stages I - VII (see also Figs. 29 and 30), n = number of fish, x = mean piece weight, A = initial biomass (kg), B = end biomass (kg), C = mean daily growth (g), D = relative change of the biomass.

1) Datum		2) Belastungsstufen						
		I	II	III	IV	V	VI*	VII
19. 8.	n	32	30	30	33	29	28	33
	x	204	218	218	199	226	225	197
	A	6.53	6.54	6.54	6.57	6.53	6.30	6.50
27.10	n	27	23	25	28	22	16	9
	x	294	311	299	281	288	312	230
	B	7.67	7.16	7.48	7.89	6.32	5.00	2.07
	C	1.32	1.37	1.19	1.20	0.91	1.28*	0.49
		0.65	0.62	0.55	0.60	0.40	0.57	0.25
	D	17.5	9.50	14.4	20.1	-3.22	-20.6	-68.2

Translation key to Table 5:

1) date; 2) loading levels

* Growth data assessed too positively because fish lost during the first two weeks were replaced. These fish were exposed for a shorter period in total.

6.2 Studies on water quality and on water exchange in commercial installations 32

6.2.1 Auetal silo installation for the rearing of fry

The first series of observations was carried out in the Auetal Fish Culture Facility. The status quo of the water conditions was recorded at several points in a few selected fish tanks under varying operating conditions

over a period of two days. The stocking densities present in the system at the time of the study are reproduced in Table 6.

As can be seen from the data, the stocking figures vary considerably, reaching densities greater than 50 kg/m^3 in tanks 1, 14, 22, 32, 33, 35 and 38 and even greater than 60 kg/m^3 in tanks 11, 20 and 31. The following tanks were selected for this study:

Becken Nr.[1]	Frischwasserzufluß[2]			theoretischer[3]
	(l/sec)	(m^3/h)	(l/kg/g)	Wasseraustausch (h)
1	1.2	4.32	6.75	2.78
18	1.3	4.68	8.00	2.56
20	1.3	4.68	6.26	2.56
31	1.5	5.40	7.47	2.22
32	1.6	5.40	8.82	2.22

Translation key to above table:

1) tank No.; 2) fresh water inflow; theoretical water exchange

The water temperature in the fish tanks was about 10°C, the pH-value in the inflow water usually between 7.5 and 7.6 with an SBV (acid bonding capacity) about and greater than 3.5.

6.2.1.1 Studies carried out

The studies on water quality and on water exchange dealt with the following factors, which were recorded in water samples taken from the inflow and outflow and, occasionally, at 21 measuring points in the fish tank: 34

Table 6: Stocking densities and quantities in the Auetal Trout Culture Facility on May 26, 1982.

1) Becken Nr.	2) Stückzahl	3) mittleres Stückgewicht (g)	4) Besatzmenge (kg)	5) Besatzdichte (kg/m^3)
1	19.400	32	640	53.3
2	11.500	44	506	42.2
3	10.900	48	523	43.6
4	5.200	77	393	32.8
5	5.600	50	280	23.3
6	-	-	-	-
7	5.700	79	450	37.5
8	-	-	-	-
9	12.300	46	565	47.0
10	-	-	-	-
11	13.700	53	726	60.5
12	3.200	100	320	26.7
13	-	-	-	-
14	21.800	32	697	58.0
15	4.600	64	294	24.5
16	-	-	-	-
17	5.500	90	495	41.3
18	7.600	77	585	48.8
19	6.700	76	509	42.4
20	6.800	110	748	62.3
21	-	-	-	-
22	8.600	72	619	51.6
23	-	-	-	-
24	4.800	75	360	30.0
25	-	-	-	-
26	-	-	-	-
27	22.900	19	435	36.3
28	-	-	-	-
29	9.600	45	432	36.0
30	-	-	-	-
31	5.700	127	723	60.5
32	5.100	120	612	51.0
33	5.500	128	704	58.7
34	5.600	110	616	51.3
35	5.600	115	644	53.7
36	5.100	103	525	43.8
37	6.300	103	649	54.0
38	4.400	113	497	41.4

Translation key to Table 6:

1) tank No.; 2) number of trout; 3) mean trout weight; 4) stocking quantity; 5) stocking density

pH-value, conductivity, acid bonding capacity (SBV), temperature, chemical oxygen demand (COD), oxygen content, ammonium and nitrite concentrations. Furthermore, the concentration and dilution rates for a dye (rhodamine B) added to the inflow were determined photometrically at 21 measuring points in tank 1 at short intervals over a whole daily cycle in order to ascertain the true water exchange times as well as the mixing of the water bodies in the fish tank with the fresh water inflow and the effectiveness of the fan pockets.

6.2.1.2 Chemical oxygen demand (COD)

The COD was determined in accordance with the German Standard Method (Dr. Hansen, Institut für Wasser-, Boden- und Lufthygiene /Institute of water, soil and air hygiene/ of the BGA /Bundesgesundheitsamt - Federal Office of Public Health/, Berlin). The COD values are slightly higher in tanks 1 and 2 but are considerably greater in tanks 14 and 18 than the limiting values which are to be permitted in the future under Section 7a of the Wasserhaushaltsgesetz /Water Resources Management Act/ (Table 7). However, it has to be taken into account that a) the data presented is based on random samples and not on 2-h mixed samples and b) these samples were taken about 0.5 to 1 hour after the last feeding. On the one hand, the COD maximum occurring in the daily cycle may have been reached in a few cases, on the other hand, these maxima may be attributable to the sudden detachment of solids deposited in

the bottom cone of the silos. Arguing for the latter possibility is the fact that the level of the COD values can by no means be correlated with the actual fish stock. The COD calculated per weight and time unit can, therefore, be considered only a momentary value.

Apart from the above-mentioned 4 silos, all of the other tanks exhibited relatively low COD values in the outflowing water at the time the samples were taken. However the COD found in the waste when the tank was drained was not recorded. The tanks are drained twice a day. Accordingly, a true assessment of the COD would be possible only if a 24-h mixed sample together with hourly random samples were studied. 36

6.2.1.3 Ammonium concentrations

The course of the ammonium curves was observed most often in tank 1. At approximately hourly intervals over a 36 hour period, two samples were taken at each of 6 points in the tank (positions 1, 5, 7 /surface/ and 15, 19, 21 /close to bottom/ /See Fig. 31/). The data is compiled in Table 8. According to this Table, the ammonium values were greater than 2.0 mg/l at all positions and at almost all times. The course of the diurnal curves for positions 5 and 19 as well as for the outflow is reproduced in Figure 32. It is striking that the maximum ammonium value is observed in the night at a temperature of 10.0°C. In the surface water of the tank, the mean of the ammonium concentrations was lowest, at 2.92 mg/l, at position 1 (close to the fresh water inflow). In contrast, the values in the middle tank range were 0.25 mg/l higher on average (Table 8), in some cases even approximately 1 mg/l higher, than in the outflow. It was remarkable that very frequently the values

Table 7: Chemical oxygen demand (COD) in the outflow of individual circular tanks of the Auetal Fish Culture Facility in the afternoon (May 27, 1982) between 4:15 and 5:40 p.m. Flow-through rates between 1.2 to 1.3 l/sec.; temperature 10°C.

1) Becken Nr.	2) Probennahme (Uhrzeit)	3) CSB - Werte mg O_2/l	mgO_2/kg/h*
1	16.15	21.0	153
2	16.23	24.0	222
3	16.28	15.0	89-134
4	16.34	15.0	119-179
5	16.39	19.0	317
7	16.44	19.0	198
9	16.48	15.0	83-124
11	16.50	15.0	97
12	16.53	15.0	146-219
14	16.55	15.0	342
15	16.57	15.0	159-238
17	16.59	15.0	95-141
18	17.01	34.0	272
19	17.04	15.0	91-138
20	17.06	15.0	63- 94
22	17.10	15.0	76-113
24	17.15	0	0
27	17.17	15.0	102-161
29	17.19	15.0	108-163
31	17.22	17.0	
32	17.24	16.0	110
33	17.27	0	0
34	17.28	0	0
35	17.30	15.0	73-109
36	17.32	0	0
37	17.35	0	0
38	17.40	15.0	94-141

4) * Für CSB-Werte um und unter 15 mgO_2/l wurden Ausgangswerte zwischen 10 und 15 mg/l zugrunde gelegt.

Translation key to Table 7:

1) tank No.; 2) sample taken (time); 3) COD values; 4) COD values of about and less than 15 mg O_2/l were based on initial values between 10 and 15 mg/l

found in the outflow were lower than those found in the fish tank. At position 5, up to 77% of the samples contained more ammonium than the values determined for the outflow (Fig. 33). The relative frequency of these values is lowest, at 37%, at position 1. This sampling point was also in close proximity to the fresh water inflow (Table 8). This distribution indicates that a) different water bodies are formed which are exchanged more poorly than others and b) that the fish were not always uniformly distributed in the tank.

The findings on the ammonium content in the outflow of tanks 18, 20, 31 and 32 are compiled in Table 9. A striking finding here as well is that in all tanks the highest values occur only during the night. The ammonium level observed in fish tank 1 must be considered slightly lower, compared to the other tanks, because the addition of rhodamine to this tank kept the animals in it generally quiet during the test period. 39

Based on the data available, even a stocking density of 50 kg/m^3 has to be regarded as too high under present technical operating conditions. Above all, the ammonium values found must be considered excessive. If we assume that about 0.025 mg/l free ammonia can be permitted as the upper limit for a short-term exposure, not repeated regularly, then, under the temperature and pH-value conditions prevailing in Auetal, the maximum values for total ammonium presented in Table 10 result. It must be emphasized, however, that these values may have to be regarded as still too high because of different test results.

Table 8: Auetal Fish Culture Facility, tank 1. Total ammonium ($NH_3 + NH_4^+$) concentration in the inflow and outflow as well as at 6 positions within the fish tank. Flow-through rate 1.3 l/sec.; temperature 10°C; fish stock 640 kg; figures in NH_4^+/l.

1) Uhrzeit	2) Positionen der Probennahmestellen im Becken (s.Abb.:31)						
26.5.82	1	5	7	15	19	21	3)Ablauf
00.20	2.21	2.45	2.16	2.62	2.63	2.33	-
08.00	2.56	2.85	2.78	2.67	2.65	2.92	-
09.25	2.80	2.91	2.87	2.83	2.90	2.67	-
10.35	2.71	2.82	2.68	2.72	2.72	2.77	2.78
11.35	2.62	2.78	2.60	2.53	2.73	2.62	2.57
12.35	2.62	2.67	2.61	2.54	2.70	2.62	2.83
13.35	1.82	2.55	2.44	2.23	2.19	2.34	1.98
14.35	2.97	3.09	3.00	2.80	3.00	2.93	3.02
16.00	2.38	2.72	2.41	2.64	2.46	2.41	2.21
17.00	3.29	3.20	2.99	3.19	3.16	3.10	3.01
18.00	3.46	3.53	3.34	3.40	3.37	3.43	3.30
19.00	3.35	3.57	3.06	2.70	3.31	2.33	3.44
20.00	2.98	3.17	3.40	3.28	3.10	3.08	3.02
21.00	3.33	3.57	3.36	3.62	3.70	3.59	3.59
22.00	3.03	3.49	3.37	3.17	3.58	3.25	3.43
23.00	3.35	3.62	3.70	3.65	3.31	3.36	3.01
24.00	3.26	2.91	3.38	2.62	3.32	2.75	2.99
27.5.82							
01.00	3.74	3.97	3.58	3.43	3.58	3.64	3.59
02.00	3.86	3.90	3.52	3.37	3.71	3.63	3.37
04.00	3.74	3.78	3.67	3.63	3.77	3.52	3.76
05.00	3.62	3.63	3.50	3.30	3.38	3.12	3.27
06.00	3.43	3.62	3.30	3.14	3.30	2.62	2.85
07.00	2.47	3.50	3.21	3.34	2.89	2.73	3.25
08.00	2.53	3.11	2.95	2.86	2.47	2.94	3.26
09.30	2.03	2.82	2.33	2.26	2.45	2.66	2.57
10.00	2.32	2.83	2.62	2.80	2.26	2.49	2.55
11.00	2.86	2.94	2.95	2.75	2.82	2.81	2.88
12.00	2.51	2.98	2.58	2.67	2.87	2.71	2.90
13.00	2.83	2.82	3.01	2.95	2.58	2.76	3.07
15.15	2.93	3.24	3.17	2.52	2.80	3.26	3.25

Translation key to Table 8:

1) time; 2) positions at which samples taken in the tank (see Fig. 31);
3) outflow

Table 9: Total ammonium ($NH_3 + NH_4^+$) concentration observed in the outflow of tanks 18, 20, 31 and 32 of Auetal Fish Culture Facility (figures in mg NH_4^+/l). Ammonium content in inflow between 0.028 and 0.030 mg/l.

1) Datum	2) Uhrzeit	3) Becken Nr. 18	20	31	32
25.5.82	22.30	[3.34]	[3.34]	2.84	3.14
		3.26	[3.46]	2.90	3.09
26.5.	08.10	2.78	2.77	1.80	1.88
		2.76	2.73	2.14	2.22
26.5.	11.15	1.80	1.47	1.73	1.84
		2.22	1.48	1.43	1.60
26.5.	12.10	2.57	2.45	2.00	1.84
		2.59	2.35	2.00	2.11
26.5.	13.45	2.85	2.68	2.39	2.40
		2.81	2.73	2.36	2.36
26.5.	14.15	2.90	2.84	2.49	2.44
		2.94	2.92	2.46	2.08
26.5.	15.45	3.09	2.89	2.91	2.67
		3.17	3.05	2.90	2.89
26.5.	16.25	[3.24]	2.88	2.88	2.71
		[3.24]	3.02	3.02	2.65
26.5.	20.15	2.49	[3.44]	[3.51]	[3.41]
		2.80	2.61	2.70	[3.46]
27.5.	00.30	[4.45]	[3.85]	[3.78]	[3.72]
		[3.98]	[3.99]	[3.73]	[3.60]
27.5.	02.00	[3.74]	3.21	2.85	2.48
		2.97	[3.78]	2.65	2.45
27.5.	05.00	[4.28]	[4.50]	[3.71]	[3.86]
		[3.61]	[3.93]	2.54	[3.54]
27.5.	06.00	[3.40]	2.90	3.00	2.96
		[3.44]	3.26	[3.47]	3.05
27.5.	07.00	[4.25]	3.21	2.82	3.13
		[4.09]	[4.23]	[3.54]	3.25
27.5.	08.00	[4.37]	[4.53]	[4.10]	[3.47]
		[4.05]	[4.46]	[3.90]	[3.83]
27.5.	10.00	[4.16]	[4.13]	[3.56]	2.71
		[4.40]	[3.96]	[3.64]	[3.78]
27.5.	12.00	[4.17]	[4.32]	[3.74]	[3.62]
		[4.44]	[4.25]	[3.85]	[3.65]
27.5.	16.10	2.68	2.90	3.26	2.89
		[3.42]	[3.72]	2.64	[3.49]

Translation key to Table 9:

1) date; 2) time; 3) tank No.

Table 10: Total ammonium concentration ($NH_3 + NH_4^+$) at which an undissociated ammonia content of 0.025 mg/l occurs under the temperature and pH-conditions given. The zone enclosed in the broken line = average temperature and pH-ranges in the Auetal facility; shaded zone = observed temperature/pH-combination on the test day.

Temperatur[1] (°C)	7.0	7.3	7.4	7.5	7.6	7.7	7.8
8.0	15.63	7.81	6.25	5.00	3.97	3.13	2.50
9.0	14.71	7.35	5.81	4.63	3.68	2.91	2.31
10.0	13.16	6.76	5.32	4.24	3.38	2.72	2.61
11.0	12.50	6.25	4.90	3.91	3.13	2.48	1.97
12.0	11.91	5.81	4.63	3.68	2.94	2.34	1.85

Translation key to Table 10:

1) temperature

According to Table 10, there were total ammonium concentrations in the tanks tested during the observation period which were no longer tolerable - at least at the times marked in Tables 8 and 9. If it is assumed that the 40
fish do not live under natural conditions, rather that they are exposed to increased social stress and general environmental stress on account of the intensive rearing, the summation effects of different environmental factors (e.g. O_2-content and nitrite concentration) which further reduce the tolerance limits for ammonium definitely have to be taken into account. American studies have shown that 0.015 mg NH_3/l was harmful to rainbow trout if the dissolved

oxygen content sank below 5.0 mg/l. Therefore, the following upper limiting values for the risk-free intensive rearing of salmonids was proposed years ago:

	NH_3 (mg/l)	NH_4^+ (mg/l)
1) Optimal	0	0.4
2) verträglich	0.005	1.0
3) Kurzzeitexposition (einige Tage)	0.025	1.6
4) Beginn des Letalbereiches	0.080	3.0

Translation key to the above Table:

1) optimal; 2) tolerable; 3) short-term exposure (a few days); 4) start of the lethal range

According to this Table, long-term exposure to concentrations greater than 0.02 mg NH_3/l should definitely be avoided.

New studies show, however, that the limiting values for long-term exposure to free ammonia should be set even lower (e.g. 0.005 mg/l) so that the observed values definitely have to result in long-term damage.

The observations on the diurnal fluctuations in nitrogen components were repeated at a later date. This time the stocking density was 50.0 kg/m^3 at a tank volume of 12 m^3 and a water inflow rate of 1.4 l/sec. Feeding 41

was carried out three times a day. The average fish size was 106.5 g. In addition to the course of the oxygen curves, especially the distribution of the ammonium concentration in the fish tank as well as the daily cycle of the ammonium value in the outflow and at some points in the tank were studied. The analyses were carried out on samples taken on a half-hour basis. Figure 34 shows the diurnal result. According to Figure 34, on account of the higher stocking density the total ammonium concentrations were somewhat higher than was the case in the observations of the previous year, especially with respect to the the exposure period. The distribution of the water bodies was improved however, as Figure 35 shows. The ammonium values in the centre of the tank and in areas in which the fish stay are below the outflow values more frequently than in earlier observations, from which one can conclude that the mixing (dilution) with the inflow water has improved. Because no improvements have been made in the inflow up to now, this effect has to be attributed to the better mixing of the water through the swimming activity of the more densely packed fish. Moreover, the improvements undertaken to the fan pockets in some cases also contributed to the more uniform distribution of the water bodies.

6.2.1.4 Nitrite values

The nitrite values in all of the tanks studied were always below 0.1 mg/l. Thus at no time did they represent a problem for the operation of the system.

As is evident in Table 11, no clear diurnal fluctuations could be observed, either. It may be assumed, therefore, that the activity of the nitrifying bacteria was relatively minor inside of the fish tanks. On account of the rhodamine B tests, no nitrite analyses could be carried out in tank 1.

Table 11: Nitrite concentration (mg/l) in the outflow of 5 fish tanks of the Auetal Facility (May 26 - 27, 1982)

Datum[1]	Uhrzeit[2]	Becken-Nr.[3]				
		1	18	20	31	32
25.5.	22.30	0.018	0.076	0.079	0.047	0.090
26.5.	08.00	0.012	0.069	0.075	0.037	0.075
	09.35	-	0.069	0.071	0.038	0.076
	12.10	-	0.068	0.068	0.036	0.076
	13.45	-	0.069	0.071	0.038	0.077
	14.15	-	0.069	0.072	0.038	0.077
	15.45	-	0.079	0.075	0.038	0.076
	16.25	-	0.067	0.069	0.038	0.078
	20.00	-	0.066	0.069	0.038	0.075
27.5.	10.00	-	0.062	0.062	0.043	0.072
	12.00	-	0.064	0.063	0.038	0.069

Translation key to Table 11:

1) date; 2) time; 3) tank No.

6.2.1.5 Oxygen content

The oxygen content of the water in tank 1 was recorded continuously at three positions (middle of the tank, at 1/3 of the radius and at the edge, in each case at about 50 cm below the surface) as well as in the inflow and

outflow. Figure 36 shows an excerpt from the tracings made by the recorder on May 26, 1982. These tracings show that the oxygen content in the outflow water decreased considerably more after the sludge on the bottom was drawn off than during feeding. In addition, the previous oxygen level was not reached again between feedings on the same day. Again, it was only during the night that there was a definite increase in the oxygen values to the initial morning value.

The oxygen findings at numerous points within tanks 18, 20, 31 and 32 showed that there were definite differences in oxygen contents in different 43
areas of the tanks (see Figs. 37 to 38). The capacity of the fan pockets appears to have been inadequate to transport sufficient quantities of oxygen-rich water into the middle section of the tanks as well. Thus, in tank 20, oxygen values greater than 6.0 mg/l were measured close to the edge. Individual values of less than 5.0 mg/l were often recorded immediately after feeding. In this regard the fish avoided the centre of the tank for a long period, often crowding together in the outer third of the tank (illustrated by the shaded area in Fig. 37). In general, it has to be noted that the oxygen level was too low to always guarantee favourable conditions for salmonids. This situation is a result of both the excessive stock and the uncontrolled hydrodynamic conditions in the fish tank. Not least, the unfavourable flow conditions were a contributing factor to the oxygen content in the outflows of the fish tanks being higher on average than in the centres of the tanks themselves. This confirms the assumption already put forward above that part of the fresh water inflow is transported directly downward in the outer area of the tank and, thus, part of the oxygen-rich water leaves the tank unused.

6-2-1-6 Studies on water exchange

A fresh water inflow of 1.2 to 1.3 l/sec. was being fed into the fish tank at the time the study was conducted. With a tank volume of 12 m^3, this means that the water volume of the tank was fed into it every 2.5 to 2.8 hours. This inflow volume did not represent the exchange of the water in the tank, however, because a substantial dilution factor had to be taken into account. In order to evaluate the real water exchange, a specific amount of rhodamine B was added to fish tank 1 continuously for 24 hours, until approximately constant extinction values had been recorded photometrically at all 21 measuring points (Fig. 39). As Figures 39 and 40 show, several unstable water bodies were formed which at times circled concentrically around the mid-point of the tank and which maintained themselves for varying periods, 44
while exhibiting clear concentration gradients. The data supported the distribution models already determined for the oxygen measurements and the ammonium findings. One can assume that water bodies remain standing for longer in the centre of the tank and are exchanged more slowly than in the areas at the edge.

The actual water exchange in the fish tanks depends not only on the distribution models of the water bodies inside the fish tanks but also on the dilution effect achieved through the continuous inflow. Figure 41 shows clearly that, in contrast to the theoretical exchange time, the true water exchange has a value increased by the factor 5. About 95% of the water is actually exchanged in 12.5 hours if the inflow volume for approximately 2.5 hours equals the tank volume.

6.2.1.7 Condition of and pathological changes in the fish not caused by pathogenic agents

These studies were carried out in collaboration with Dr. G. Peters (IHF, Hamburg).

Condition and growth rate: On May 28, 1982, the trout in tank 1 had a mean weight of 24.74 $\pm$ 10.96 g per trout. The size of the random sample on which all of the measurements were based was n = 51. The minimum weight was 16 g, the maximum 50 g. The Furkal[tn] length was 12.74 $\pm$ 1.00 cm on average (minimum 10.7 cm, maximum 15.3 cm). From which, a condition factor $K = 1.28 \pm 0.22$ is calculated, which is in the normal range considering the small size of the fish.

The specific growth rate ascertained using the available data (α = 2.10%) is about 10% less than that for the fish previously studied from the same facility. This is far behind (40%) a good net preserve growth.

The spleen somatic indix (MSI): The MSI, which allows statements about the strains experienced by the fish due to stress or systemic illnesses (e.g. infections), is unremarkable at $\bar{x} = 0.147 \pm 0.039$. 45

Liver somatic index (LSI) and liver findings: The livers of the fish studied are swollen. Their somatic index is double that of other intensive culture trout ($\bar{x} = 2.454 \pm 0.488$). It also exceeds considerably the index of the previously studied trout of the Auetal Fish Culture Facility. In addition, the livers exhibit yellowish orange transparent changes; the consistency of

[tn] translator's note: I have been unable to find an English Equivalent for this German term.

their tissue is soft in many cases. These findings point to disturbances in the fat or protein metabolism.

Gill findings: The gills of the fish studied exhibit considerable damage: on average, more than 75% of the primary lamellae are distal histolytic, necroses are found in a third of the trout. All of the animals have large hyperplasias of the secondary lamellae, which often result in total loss of the pinnule structure. The vessels of the secondary lamellae are distal hyperaemic in all of the trout.

The findings are more marked than was the case with the fish previously studied from the same facility. They are not based on parasitic damage. They may point to a temporary or permanent intoxication or auto-intoxication by ammonia. The lesions impair respiration and excretion and, as a result, reduce the growth of the fish.

Morphological anomalies: In more than 52% of the trout, an exophthalmos is found on the left side, in 23% on both sides. Forty-five per cent of the fish exhibit gill cover reductions. Neither finding can be interpreted satisfactorily at present.

The dorsal fin is shortened in 70% of the fish. It is to be assumed that this impairment is caused not only by mechanical factors (bumping against the walls of the silo). Rather, the tissue degeneration may be caused by inadequate water quality and the resulting poor oxygen supply of the exposed fin tissue.

6.2.1.8 Conclusions and recommendations

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Based on the data available, it was recommended that the installation undertake technical adjustments in the operational system in order to reduce

greatly the existing risks from occasional toxic exposure of the animals to ammonium with simultaneous reduction of the oxygen content. The following measures, among others, were proposed:

1) The screening-out of fine grit from the feed prior to use should definitely be retained. This reduces substantially the organic contaminants in the fish tank and the related oxygen consumption. Furthermore, automatic feeding machines should not be used: they would only increase the grit and, as a result, the percentage of suspended solids, in particular at times when the feed is not completely consumed.

2) The fresh water inflow should definitely be increased, even doubled if possible.

3) In order to distribute the water bodies better and to reduce the concentrical circulation of some water bubbles, it was recommended that a central standing cylinder be installed, reaching to the bottom of the tank cone, and that the screen plate be replaced by a solid plastic base plate.

4) The bottom apertures of the fan pockets should be completely closed. If the water circulates over the bottom apertures of the fan pockets, there is a danger that rapidly sinking coarse solids (e.g. coarse pieces of intact fecal material) will be drawn in through them, ground finely in the ventilation flow and then re-suspended.

It is expected that these measures will lead to substantial improvements in the overall operation.

6.2.2 Kellinghusen Trout Fattening Facility

In contrast to the Auetal facility, the circular tanks in Kellinghusen have a much larger diameter, a central standing cylinder and no fan pockets installed on the outside. A central liquid oxygen unit supplies all tanks uniformly. It is not possible to adjust the oxygen content in each tank individually. The tests were carried out in November 1982.

6.2.2.1 Distribution of water bodies in the fish tank

In this case, as in Auetal, the distribution of water bodies was determined by taking multiple samples at 19 measuring points in a half cross-section of a tank. At first, the tank inflow and outflow were checked at the same intervals. The water samples for the ammonium and nitrite measurements were taken hourly, simultaneously at all points. Parallel to this, oxygen profiles were recorded in several tanks by taking multiple measurements at 26 measurement points with the aid of an oxygen electrode (orbisphere).

Figure 42 shows the test results for the distribution of the mean oxygen concentration in different tanks. According to Figure 42, the water bodies are relatively well mixed under the given operating conditions (stocking density, inflow volume). The available data indicates, however, that slightly lower oxygen values occur in several areas of the tank, especially the second third of the radius (in which the fish usually stayed during the observation period), while relatively high oxygen contents are observed in the central section of the tank and at the edge. Based on the relatively low stocking density during the observation period, the differences in the oxygen values are low, as expected. With full stocking, however,

it must be expected that the water exchange is not as uniform and that oxygen values fall substantially. In general, one was struck by the fact that the oxygen content in all tanks was terribly high during the observation period, often rising to 200% of the saturation value. In this case, the regulation of the oxygen content or the flow-through should be improved in conformity with the relevant stocking density. Unfortunately, the oxygen enrichment is carried out directly in the inflow as a whole and not in bypass (separated for individual production lines) so that it is not possible to regulate the oxygen content individually. 48

6.2.2.2 Ammonium and nitrite

As Figure 43 shows, ammonium values varied considerably throughout the daily cycle, despite a relatively low stocking density (low in comparison to the operator's data on stocking densities already attained and low in comparison to the Auetal facility). The maxima occurred primarily in the late afternoon and night hours. In general, the ammonium concentrations were higher than was to be expected, given the existing stocking densities. This was mainly due to the already high initial concentrations in the inflow water. The values in the inflow fluctuated between 0.7 and 0.9 mg/l. These values indicate that the effluent load in the receiving waters and in the flooded gravel pit is no longer fully treated and is overtaxed as a cleaning system for the recycling operation.

The distribution of the ammonium values within the large circular tanks did not vary greatly from the outflow concentrations. However Figure 44 shows occasional water bubbles in the outer sections of the tank having

ammonium concentrations far greater than the outflow values. Such bubbles were found in 37 to 47% of the measurements taken at two measuring points in the peripheral areas of the tank. In contrast, the ammonium values in the central cylinder (with the exception of the measurement position close to the outflow) were greater than the outflow concentrations in only 21 to 26% of the random samples. These observations show better distribution models, in comparison to the test results for the Auetal facility. They are attributable to a) the relatively low stocking at the time of the test and b) to the favourable effect of the central cylinder on the circulation. 49

6.2.2.3 BOD load

In order to obtain information on the BOD load in the various systems of the installation, a few samples were taken. The data is presented in Table 12. More extensive studies on the BOD and COD would have to be carried out over a long period in order to quantify the distribution of the loading within the system and its effects on the receiving waters (pond and lake). The dissolved BOD value is slightly less than 10 mg O_2/l in the outflow of tank D3 and at the oxidator outflow; it increases somewhat in the settling tank. The unfiltered sample shows a value greater than 10 mg O_2/l in the settling tank and even higher at the pumping station in the adjacent lake. The samples for the BOD measurement were taken between 12.00 a.m. and 1.00 p.m. and very probably do not represent the loading maximum in the daily cycle. The BOD values are slightly increased but are tolerable if other pollutants are not increased at the same time.

The differences between filtered and unfiltered samples make clear that the suspended matter contributes greatly to the organic load, and it is recommended that these solids be removed from the system as early as possible.

Table 12: Orientation BOD values in the Kellinghusen facility. Samples taken from 12:00 a.m. to 1:00 p.m., two samples in each case. 50

3) Probe	1) O_2-Gehalt 4) sofort	2) BSB (mg O_2/l) 5) nach 4 Tagen	6) nach 5 Tagen
7) Auslauf Becken D3	14.2	8.7	8.5
8) Oxidator	15.4	7.6	8.2
9) Absetzbecken			
10) -filtriert	11.4	7.9	8.4
11) -unfiltriert	10.5	10.5	?
12) Pumpstelle, See			
10) -filtriert	11.4	7.4	7.9
11) -unfiltriert	11.9	11.9	?

Translation key to Table 12:

1) O_2-content; 2) BOD; 3) sample; 4) immediately; 5) after 4 days; 6) after 5 days; 7) outflow tank D3; 8) oxidator; 9) settling tank; 10) filtered; 11) unfiltered; 12) pumping station, lake

6.2.2.4 Studies on the removal of suspended matter

Since part of the water discharged from the system is recycled through the adjacent pond, the removal of solid matter is very important with regard to the pollution of receiving waters. The design of the existing settling tank is such that it is unsuitable for effective removal of suspended matter. The turbulence occurring in it is so great that even coarse pieces of fecal material frequently "slip through". For technical and cost reasons, the operator of the system is unable to remodel the settling tank or replace it with another. The settling of solid material is, however, also affected unfavourably

by the turbulence experienced on the long path through the pipes and by the impact of the water on the bottom of the overflow pipe. It breaks into small pieces, or rather, is shattered upon impact. In the process, large amounts of BOD go into solution, especially from the feces, loading the secondary settling ponds, where they settle much more poorly. The observations described below are intended to make it possible to assess the expected efficiency of sediment traps, which can be connected directly behind the individual large tanks.

6.2.2.4.1 Solid material 51

In order to assess the load that can be removed from the system if relatively simply designed sediment traps are installed in close proximity to the place where the solids originate, settling samples (two-litre samples, 15 minutes settling time) were conserved and the dry weight determined. The results are shown in Table 13. The data show the quantity settled within 15 minutes and the amount of suspended matter which could not be settled during this period. According to this data, between 80 and 90% of the solid matter can generally be removed during retention periods of 5 minutes (standing water). The data shows roughly that approximately 0.5 kg dry matter can be removed per day and per tank at a flow-through rate of 3.6 m^3/h. It is to be assumed that at the time of the tests the existing stock was far below the calculated maximum, thus considerably higher solid material loads occurred during other operating times. If one assumes that only 10 tanks are equipped with sediment traps, it is estimated that with a mean stock of 2.9 - 3.6 tons of fish, 0.35 to 0.55 tons of sludge, on a dry-weight basis,

would be removed per month which would not pollute receiving waters. Where the system is fully stocked, this would represent solid matter of more than 15 tons per year. Since,practically speaking, this is a recycling system which uses an open body of water (a flooded gravel pit) as a treatment system, special importance is attributed to this major loading factor. There is acute danger of the hypereutrophication of this body of water and, thus, a not inconsiderable risk for the recycling operation of this system.

6.2.2.4.2 Settling behaviour

Several samples were used to investigate the settling behaviour of suspended matter in the outflows of two tanks. Three particle sizes were distinguished visually: a) very coarse particles (mainly large pieces of intact fecal material), b) particles of medium size (broken pieces of feces, disintegrated feed residue) and c) fine, difficult-to-settle components. The 53
first two categories come under the particles described in the previous section which settle in 15 minutes. Table 14 contains the results.

6.2.2.5 Recommendations on technical operating measures to improve water quality 54

The following immediate measures were recommended:

1) A definite reduction in the inflow oxygen concentration. At times, the oxygen concentrations determined were at toxic levels.

2) The installation of sediment traps directly behind the tank outflows.

3) A change in the design of the tank inflow, in order to distribute the fresh water better.

Table 13: Dry weight of sludge in the outflow water of some fish tanks of the Kellinghusen facility and estimated values of the daily solid matter load under different conditions a) amount that cannot be settled in 5 minutes; b) solids settled within 5 minutes. n = number of fish in the relevant tank, $\bar{x}$ = average individual weight.

6) Becken	n	1) Volumen (m^3)	2) Fischbesatz (kg)	$\bar{x}$(g)	3) Zufluß (m^3/h)		4) Tageszeit 8.45	9.30	5) (Schlammtrockengewicht (mg/l)) 10.45-11.25	12.20-13.10	14.50	17.00
D2	12000	100	3600	300	3.6	(a)	0.014	0.057	0.008	0.012	0.008	0.012
						(b)	0.160	0.100	0.102	0.292	0.303	0.198
D3	18500	100	2940	159	3.6	(a)	-	0.026	-	0.001	0.030	0.007
						(b)	-	0.104	0.208	0.048	0.090	0.081
D4	4740	100	1800	380	3.6	(a)	-	-	-	0.001	-	-
						(b)	-	0.062	0.120	0.108	-	-
C6	19000		932	49		(a)	-	0.016	-	-	-	-
						(b)	-	0.068	-	-	-	-

Translation key to Table 13:

1) volume; 2) fish stock; 3) inflow; 4) time of day; 5) dry weight of sludge; 6) tank

Table 14: Settling of solids from the tank outflow and from the settling tank of the Kellinghusen facility. Three tanks containing a mean fish stock were selected.

		1) Absetzgeschwindigkeit (cm/min) 2) Partikelgröße		
3) Rundbecken	4) Tageszeit	5) grob	6) mittel	7) fein
D2	8.35	25.6	8.53	2.65
"	"	24.0	-	4.66
D2	9.30	28.3	11.60	4.03
D3	8.45	20.2	9.40	4.47
"	"	-	-	4.13
D3	9.30	18.5	12.00	2.40
"	"	21.2	-	-
D4	9.30	20.4	9.03	1.81
"	"	16.5	-	-
C6	9.30	-	9.44	3.29
"	"	-	9.28	3.52
Absetzbecken	15.25	8.3	5.12	4.49
"	"	11.3	5.77	-
"	"	13.2	8.44	3.64
"	"	-	-	4.22
"	"	-	7.38	3.61
"	"	-	5.69	-
"	"	-	4.80	-
"	"	-	5.33	-

Translation key to Table 14:

1) settling speed; 2) particle size; 3) circular tank; 4) time of day; 5) coarse; 6) medium; 7) fine; 8) settling tank

7. Evaluation of the Water Treatment Process and its Integration into the Fish Culture Recycling System 55

The treatment of fish effluent in a recycling system is not without problems, despite the fact that it involves the treatment of "natural" and not of "industrial" effluent. It was shown repeatedly that even where the reduction efficiency of the bio-filter is high, the relative composition of the contaminants in the outflow water of a treatment unit is at least slightly different than in the inflow water. One can assume that all of the contaminants easily reduced by microbes are treated in the bio-filter in the main, while the remainder is composed to a not inconsiderable degree of hard-to-reduce organic substances. In a flow-through settling facility, these remaining contaminants would be released into the receiving waters and treated or diluted after a reasonable delay. In a recycling system, they remain in the system, shifting the composition in favour of the hard-to-reduce components with every circulation. The concentration rate of these hard-to-reduce substances (measured by the COD for example) depends on the fish species, the stocking density, the feed composition, the temperature, the water exchange rate in the system, the efficiency of the bio-filter and on the concentration of numerous effluent components (In the last analysis, the kinetics of many degradation processes is dependent upon the substrate.).

Scherb and Braun (1971) were the first to prove that not all of the effluent components concentrated in the recycling water of an almost completely closed recycling system with solely biological water treatment are reduced. This concentration can be counteracted effectively through the use of chemical treatment processes, like, for example, the bypass ozonization

used by us. The system concept (combined bypass recycling systems: "multiple cycle system") already developed in the preceding project (MFE 0503/8) has continued to prove itself.

As a prerequisite for optimization of the treatment steps, it was necessary to separate the water flow for independent control of individual system components. In the project completed, we were able to deepen our understanding of the effect of those environmental factors which determine the extent of the dynamics of fluctuations in water quality under experimental and commercial operating conditions. 56

The following conclusions can be drawn from the test results obtained up to now and from the data presented in the technical literature:

1) In principle, fish culture is possible in almost completely closed recycling systems. The essential criteria for the control of water quality are generally known.

2) The economic efficiency of such processes cannot be proven at present, because they depend on numerous technical and site-related factors, among other things, which have been studied insufficiently up to now (especially with respect to the unreliable projection of the results from small test systems to large semi-industrial or commercial systems).

3) High demands, exceeding the reduction efficiencies of conventional purification technologies, have to be made of the treatment units of almost completely closed recycling systems.

4) The concentration of hard-to-reduce substances can be counteracted through the use of bypass ozonization. It can also support the

sensitive second stage of nitrification in the biological filter through quantitative oxidation of the nitrite to nitrate under large fluctuations in load.

5) The use of combined treatment processes in the "multi-cycle-system" cannot completely prevent fluctuations in the concentrations of individual toxic effluent components. The amplitude of these fluctuations depends greatly on the stocking density however. 57

6) These fluctuations can, however, be minimized by suitable technical operating methods. These include, among others, a) the daily adjustment of flow-through rates through fish tanks and bio-filters corresponding to the course of the excretion rates for metabolic end products and their distribution (dilution) throughout the whole system, b) the intermittent use of oxidation processes (ozonization) and c) the prior removal of solids (feces and feed residue).

7) The efficiency of carbon reduction in fish culture recycling systems using trickling filters as biological treatment units is similar to that in conventional purification systems with high pollution loads.

8) In low-rate trickling filters and rotating drum reactors, the nitrification processes appear susceptible to breakdown in the treatment of fish effluents where the load varies.

9) The concentration of nitrate in the closed system can be counteracted through the installation of an anaerobic denitrification stage operated in bypass. Its operation can be better stabilized through direct feeding-in of the fish effluent than through the use of water

from the biological secondary purification. The addition of specific quantities of another carbon source cannot be waived.

10) Based on the knowledge available up to now, the results of the operation of almost completely closed recycling systems are applicable only to warm water conditions (temperatures above 22°C), because the degradation processes often proceed too slowly at low temperature ranges, in contrast to the concentration processes of metabolic end products, and therefore need disproportionately large volumes to counteract these concentrations. 58

At present, it can only be recommended that in practice the use of recycling systems be limited, wherever possible, to half-open systems in which the concentration of hard-to-reduce substances can be counteracted through dilution. Whether almost completely closed systems will be used in practice in the future will depend not only on local site factors and other market-related criteria but also on the gradual, logical continuation of the development from pilot projects to large, commercially realistic production modules. If this deliberate progression from basic research to practical use, including the associated multi-disciplinary research, is not carried out, it is to be feared that a) potential users will continue to invest too early and too liberally in this young industry and run aground and b) the technological lead will be quickly made up by other industrial countries which will use their technological advances to dominate the market.

The setting-up of almost completely closed recycling systems for intensive aquaculture will become much more important in the future, above all in the rearing of spawn and stock. Such systems offer an opportunity not

only to rear spawn under controlled environmental conditions but to generally adjust the environmental conditions to that water quality in which the spawn bred should grow to market size, an aspect which has been largely ignored up to now in assessing the success of stocking measures.

For general research, as well, for example in the fields of nutritional physiology, genetics, toxicology, reproduction biology, stress research and pathology, recycling technology - if sufficiently standardized - will be able to provide specific conditions which improve the reproducibility of test results and make their interpretation more reliable.

In connection with the recommendations of various international organizations, it will be necessary in future to improve national controls on the often ticklish problem of the transfer of indigenous and exotic species for aquacultural and stocking purposes in order to counteract effectively the transmission of diseases. In this regard, recycling technology has to be used to operate quarantine stations. 59

In the near future, with the further intensification of aquaculture, the prospects of a successful economic and technically safe use of recycling technologies will depend on whether it is possible a) to develop individual system components in such a way that they can be optimally used under practical economic conditions, b) to set down strategies for the faultless operation of such systems which take into account adequately the basic requirements of the species in question and c) to train the scientific and technical personnel to be employed specifically for the special requirements of this specific branch of aquaculture.

The question of what requirements individual fish species, as potential candidates for intensive aquaculture, will make on the water quality remains largely unanswered. Although numerous toxicity studies have shown us the tolerance limits for short-term exposure to individual effluent components (e.g. nitrite, ammonium, pH-value), we know hardly anything at all regarding how other pollution values (e.g. COD, BOD, TOC) work and how the combined effect of effluent components on grwoth, mortality rates and product quality is to be evaluated in the long run. This represents an important research endeavour for which recycling technology provides good experimental conditions.

Applicable initially as a hobby, in future the industrial production of aquatic animals will only reach fruition if measures to promote it are increased right now. The relevant institutions will have to make the results 60
of application-oriented research available to practical users at an appropriate demonstration level (e.g. pilot system of relevant size with possibilities for enlargement).

8. Summary

These studies on the use of recycling technology in intensive fish culture had as their objective to record the performance data for individual system components under dynamic conditions and to test their use in a "multi-cycle-system", using different treatment processes. The studies produced the following results, among others:

1) High demands, exceeding the degradation efficiencies of conventional purification technologies, are to be made on the treatment units of almost completely closed recycling systems.

2) The water quality fluctuates dramatically in intensive fish culture on account of the daily rhythm of the metabolic activity of the fish.

3) The diurnal fluctuations in water quality affect the treatment efficiency of the biological filter greatly.

4) Biological filters can be stabilized best by adjusting the hydraulic load to the course of the diurnal curves for different water qualities.

5) The run-in phase for low-rate trickling filters is relatively short; however permanently stable nitrification operating phases can be established only after many months of operation.

6) Low-rate biological filters react more quickly to minor fluctuations 61
in load than relative high-rate systems. As the inflow concentration increases (e.g. ammonium and nitrite), the oxidation in both systems decreases rapidly at first. However low-rate systems exhibit a smaller range of variation in the outflow values in normal operation.

7) Different substrates exhibit hardly any differences in the surface-related nitrification. Related to the filter volume, such differences in performance are substantiated however.

8) An anaerobic bypass denitrification stage integrated into a fish culture recycling system can be stabilized better on a long-term basis if the carbon source is made up in part of fresh, settlable

organic material taken directly from the fish tank outflows. The addition of methanol is also necessary.

9) The concentration of hard-to-reduce substances can be counteracted with bypass ozonization. BOD and nitrite can be easily oxidized in the contact tower, which has different dimensions, while ammonium is oxidized only very inefficiently. Data was worked up which can be used to calculate the operating conditions of a bypass ozonization system to completely oxidize peak nitrite load.

10) From the performance data of the bypass ozonization studied, it can be seen that integrating an ozonization unit into the fish culture recycling system supports at least the second stage of nitrification in the biological filter by oxidizing nitrite to nitrate quantitatively where large fluctuations in load occur.

11) Although the use of the combined treatment processes in the "multi-cycle-system" does allow the fluctuations in concentrations of indi- 62
vidual toxic effluent components to be levelled out in the main, these fluctuations cannot be completely prevented. This does not appear necessary from a biological point of view, either. However, there are considerable gaps in our knowledge of the tolerance limits of cyclically fluctuating water qualities.

12) The layout and operating form of the holding units (fish tank) contribute greatly to the amplitude of the fluctuations in effluent values. These influencing variables can be stabilized considerably through appropriate technical operating measures.

13) The water exchange in circular tanks and silos is often influenced by the swimming behaviour of the fish. This applies especially to the mixing and distribution of water bodies. High stocking densities generally provide for better mixing of the culture medium in rearing tanks but usually increase the concentration levels of various water values as well as the amplitude of the diurnal fluctuations.

14) Almost completely closed recycling systems (except for use in aquarium technology) will become much more important in the near future, above all in the rearing of spawn and young fish. It will also be available for use in general research everywhere where extensive standardization of the rearing conditions is required in order to improve the reproducibility of test results.

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Appendix: Figures

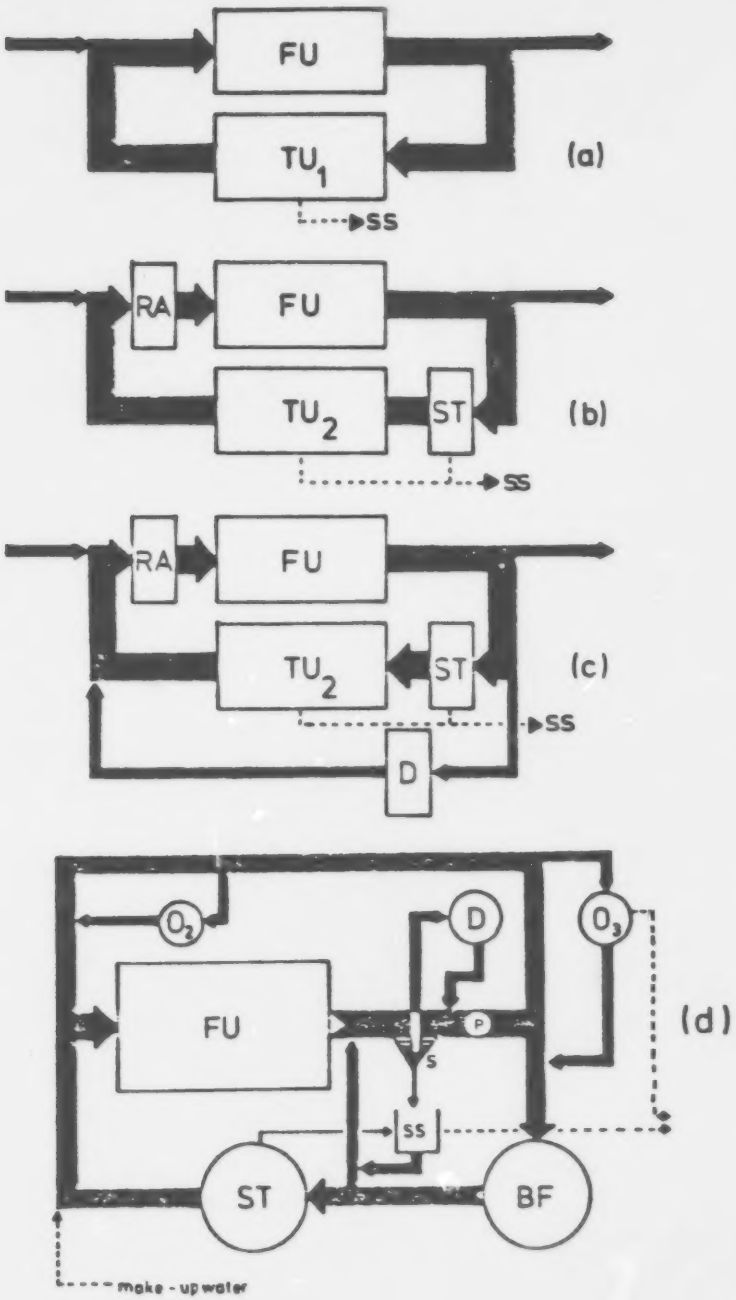

Fig. 1: Basic trends in the development of almost completely closed recycling systems for fish culture. a) = simple recycling system with conventional alignment of the biological treatment; b) = conventional recycling system with a mechanical treatment unit operating in advance of it and an aeration unit operating behind it; c) = recycling system with additional bypass for anaerobic nitrogen elimination; d) = "multi-cycle-system" with several sub-recycling systems for separate control of individual treatment processes. F = fish culture; TU_1 = treatment unit (e.g. gravel filter); TU_2 = treatment unit (e.g. activated sludge or fixed-bed filter); ST = settling tank; RA, O = aeration or oxygen enrichment; D = denitrification stage; SS = sludge collector; S = sediment trap; BF = biological filter; P = pump

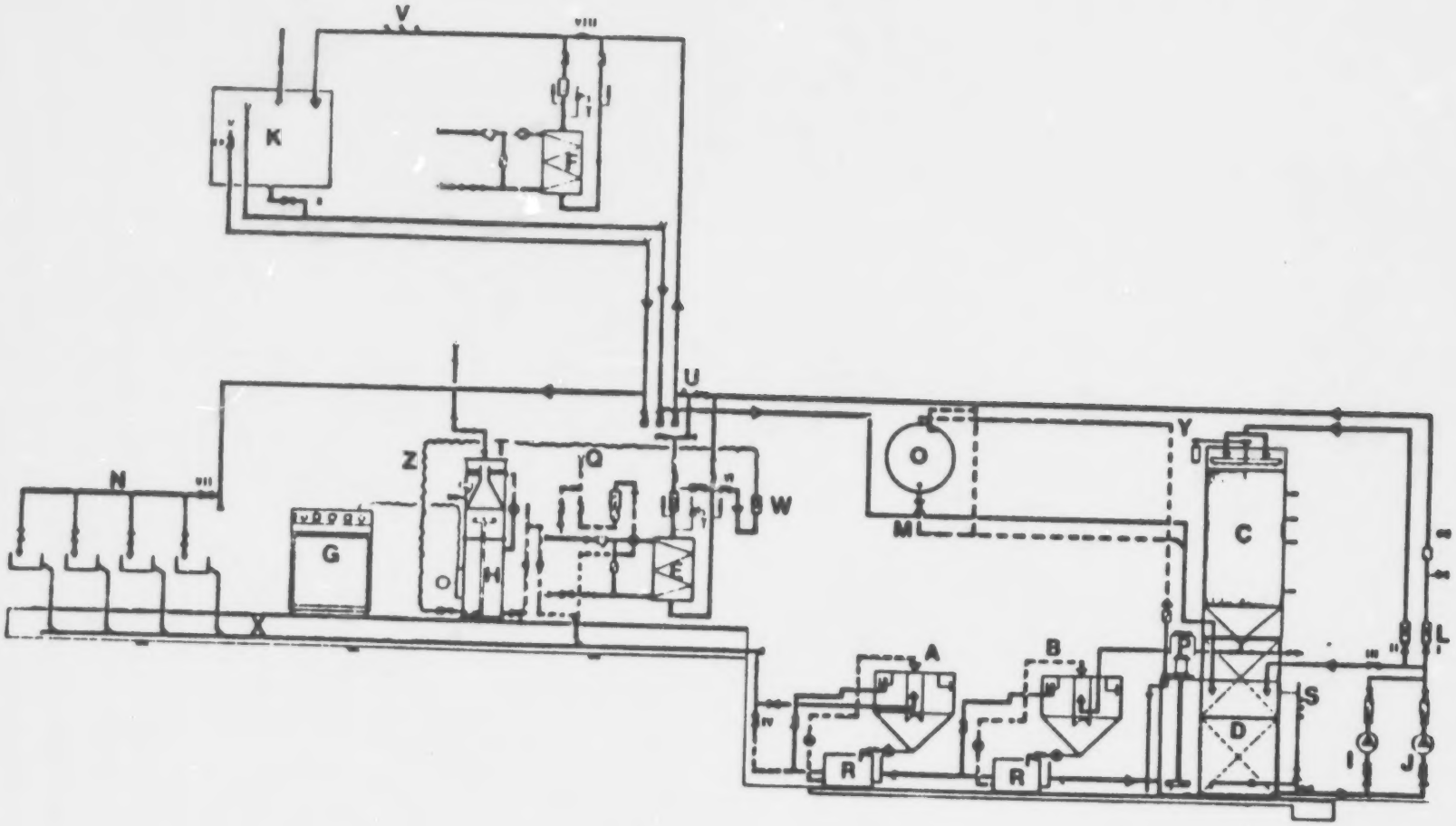

Fig. 2: Diagram of the layout of the sea-water recycling system in the Zentrale of the Biologische Anstalt Helgoland, Hamburg. See text for explanation.

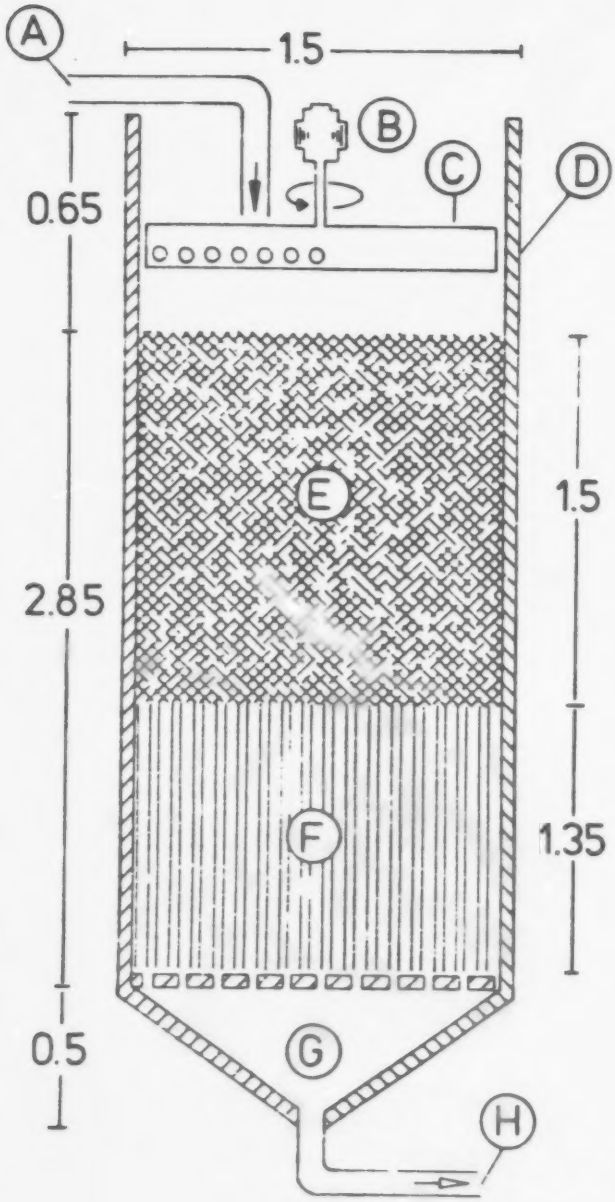

Fig. 3a: Layout of the trickling filter with combined filling material charge. A = inflow; B = motor; C = rotary sprinkler; D = outer wall; E = BIO-NET filling material; F = Hydropack foil; G = collecting funnel; H = outflow; dimensions given in meters.

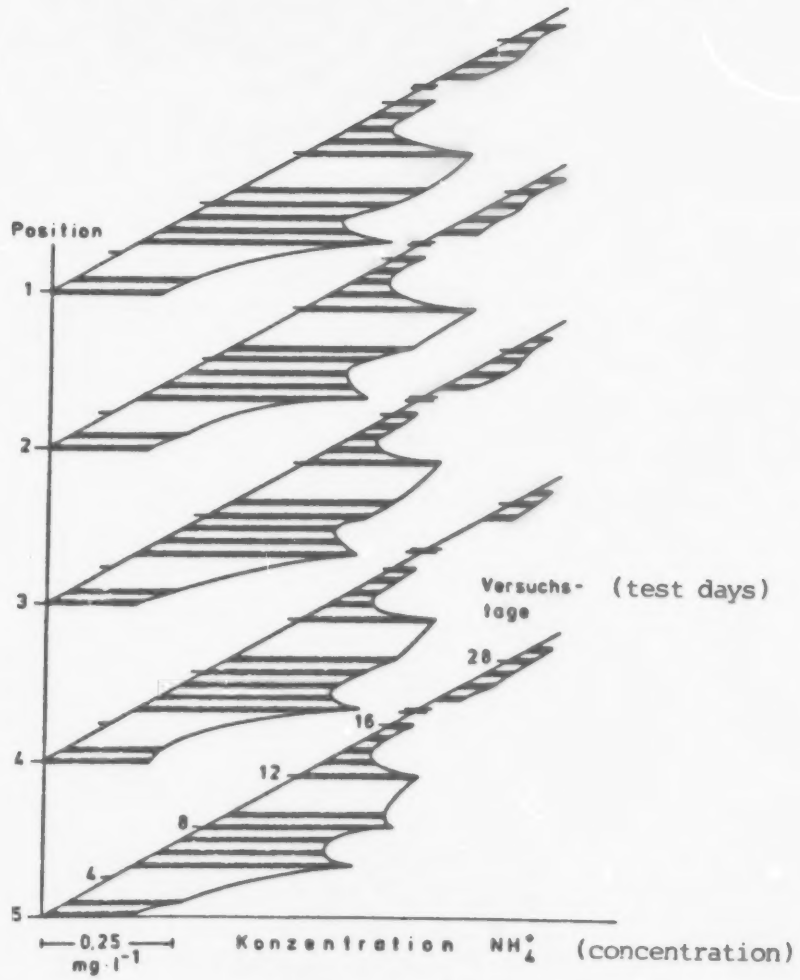

Fig. 3: Course of the ammonium curve at different depth horizons during the run-in phase of a trickling filter with BIO-NET material (upper layer = 150 cm) and Hydropack foil (lower layer: 135 cm) as yardstick for the development of the operating method of the first nitrification stage. Y-axis = positions of the sampling sites; 1 = inflow; 2 = 50 cm; 3 = 95 cm and 4 = 115 cm below the substrate surface; 5 = outflow

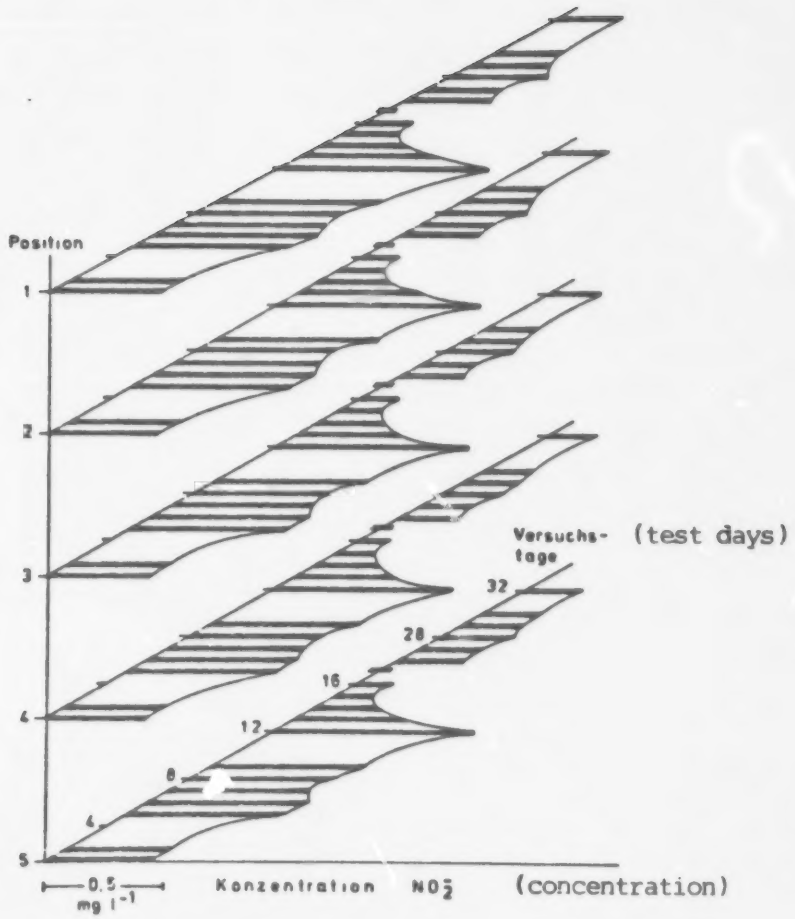

Fig. 4: Course of the nitrite curve at different depth horizons during the run-in phase of a trickling filter with BIO-NET material (upper layer = 150 cm) and Hydropack foil (lower layer: 135 cm) as yardstick for the development of the operating method of the second nitrification stage. Y-axis = positions of the sampling sites; 1 = inflow; 2 = 50 cm; 3 = 95 cm and 4 = 115 cm below the substrate surface; 5 = outflow

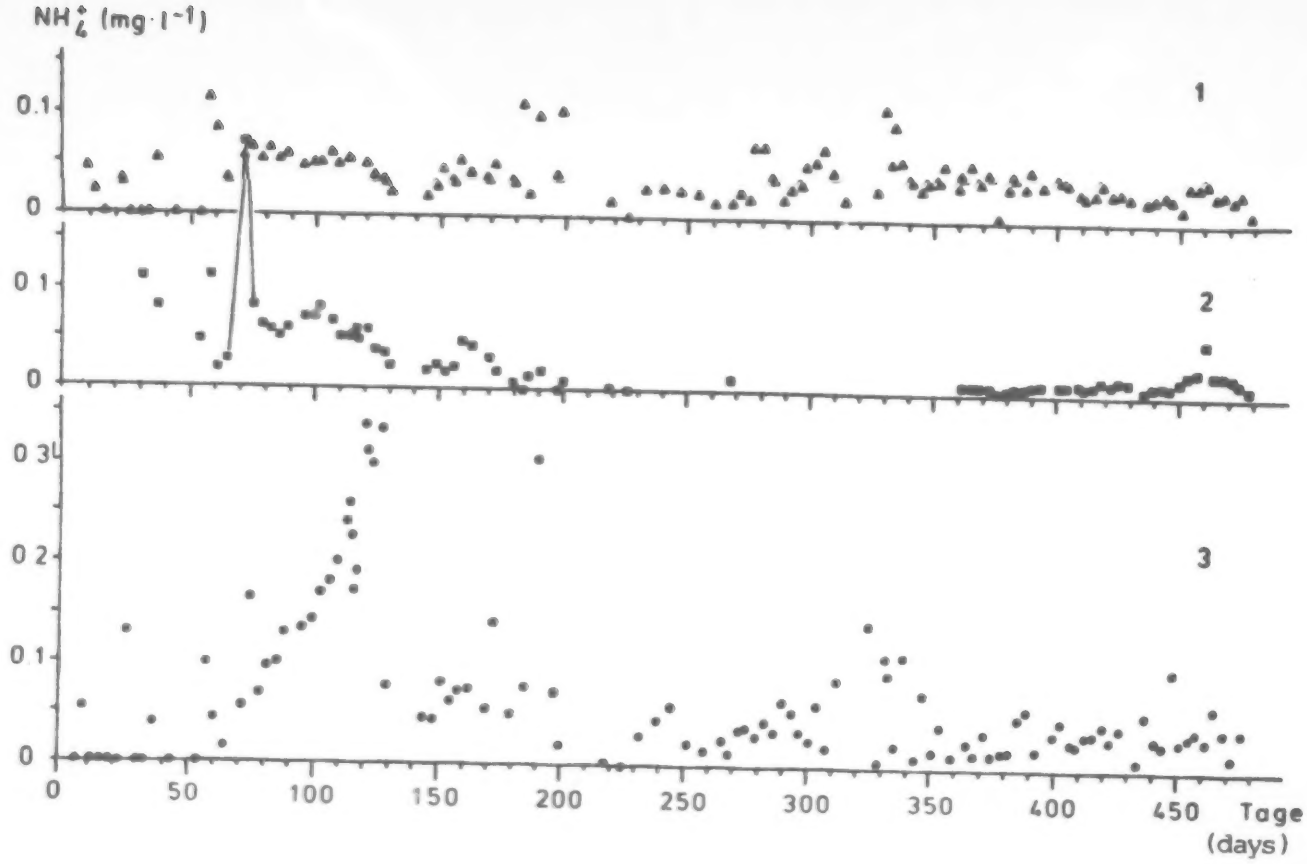

Fig. 5: Series of long-term observations on water quality in three recycling systems with different fish stocks. The ammonium concentrations in the inflow water of the fish tanks are illustrated

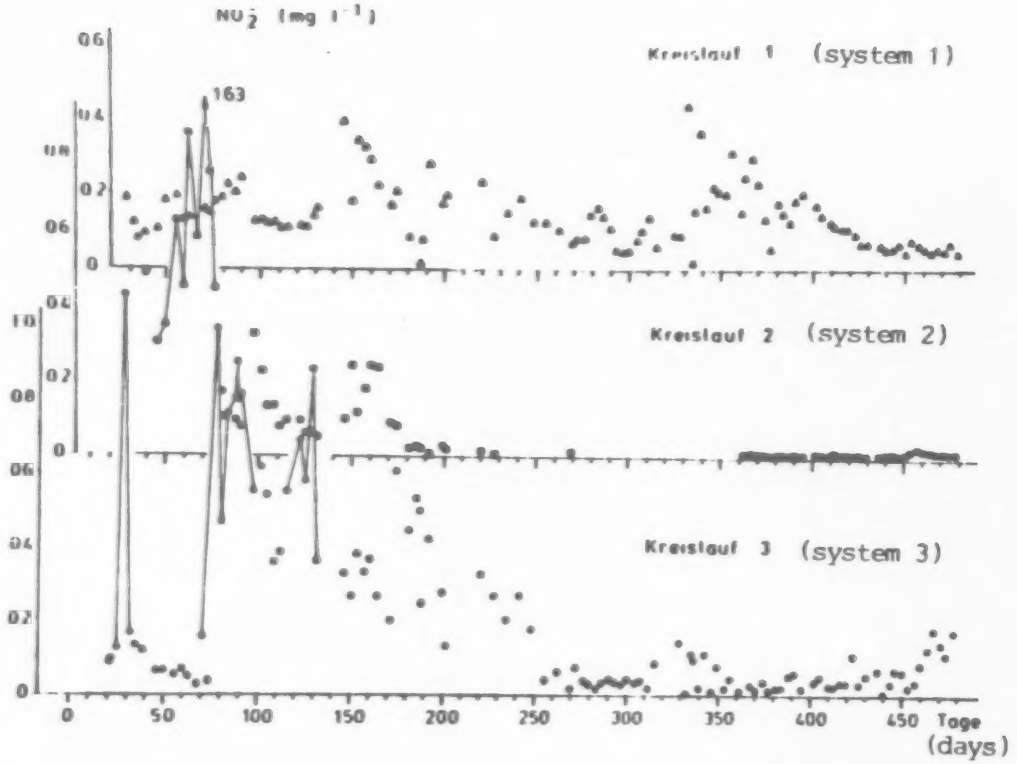

Fig. 6: Series of long-term observations on water quality in three recycling systems with different fish stocks. The nitrite concentrations in the inflow water of the fish tanks are illustrated.

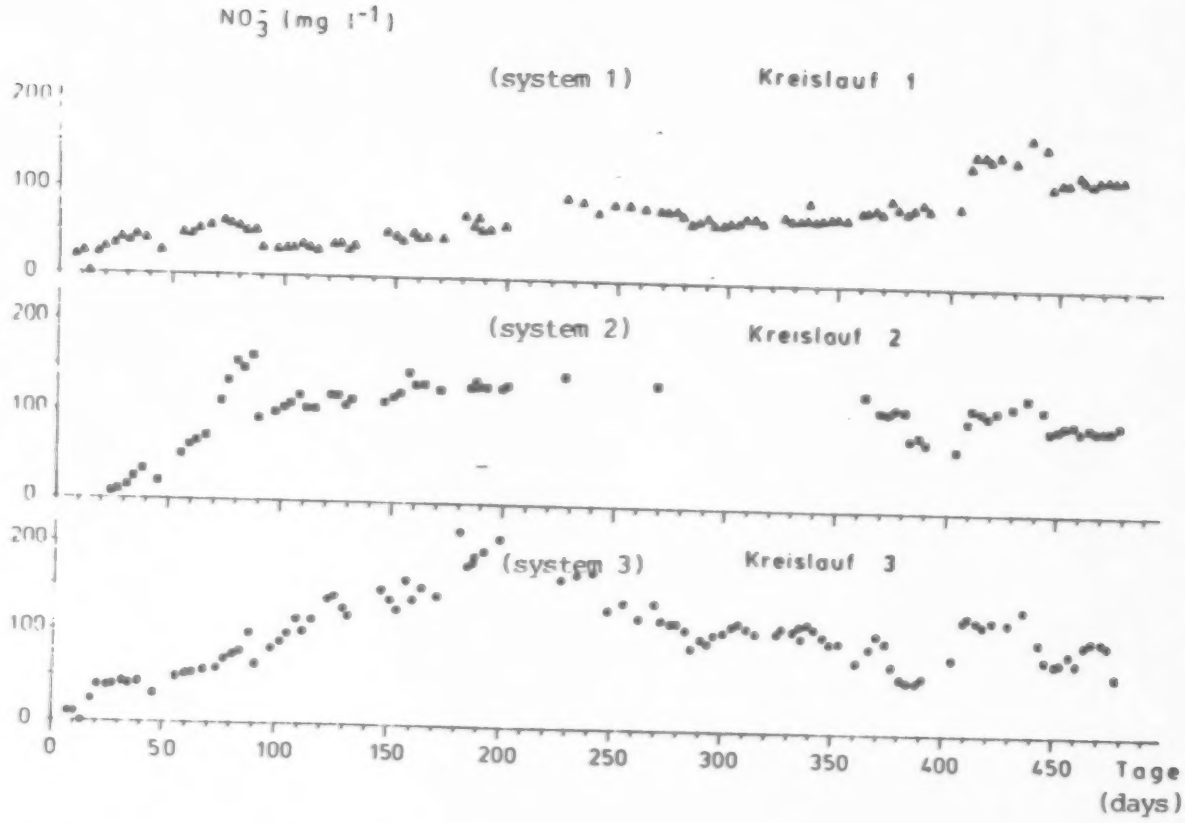

Fig. 7: Series of long-term observations on water quality in three recycling systems with different fish stocks. The nitrate concentrations in the inflow water of the fish tanks are illustrated.

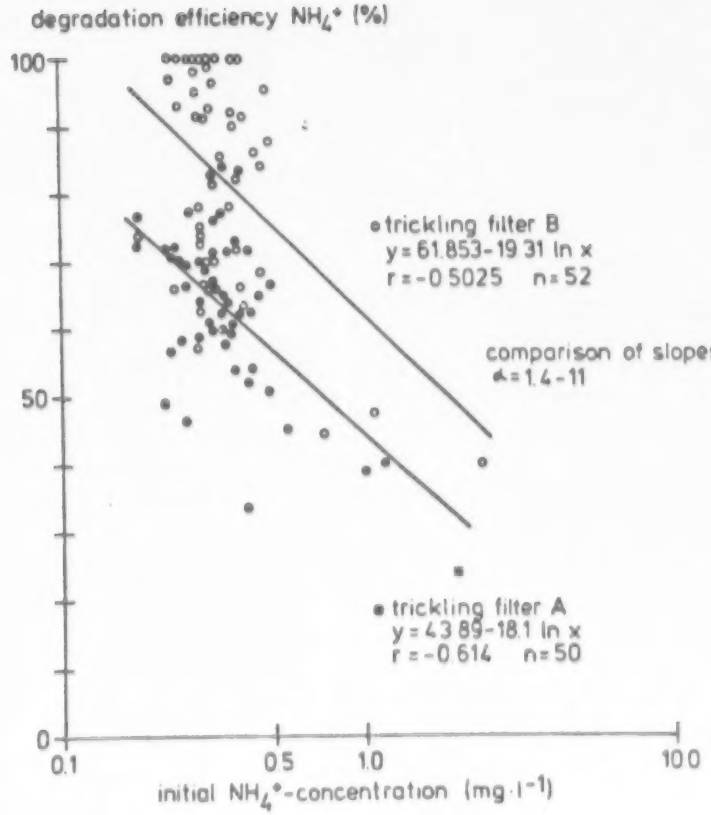

Fig. 8: Comparison of the total ammonium degradation efficiency of two trickling filters with different substrates in relationship to the inflow concentration.

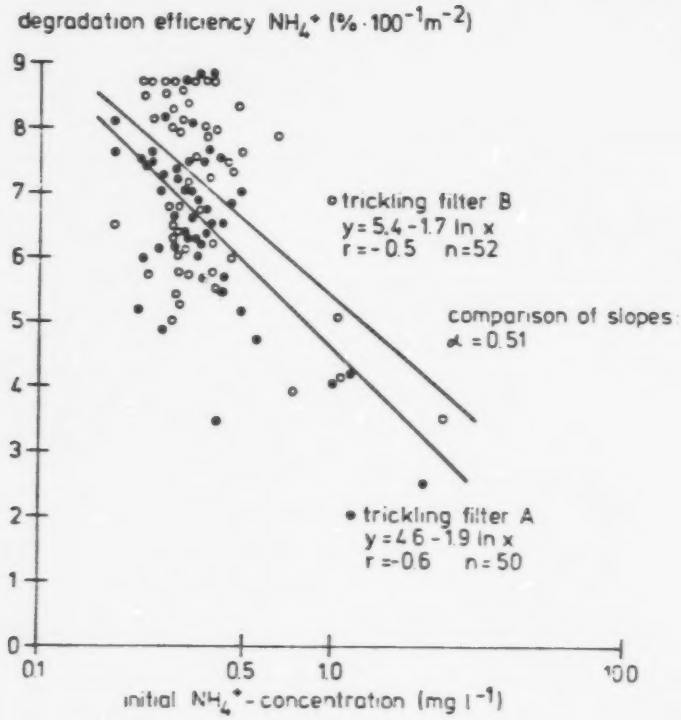

Fig. 9: Comparison of the total ammonium degradation efficiency per 100 m^2 of substrate surface of two trickling filters with different substrates in relationship to the inflow concentration.

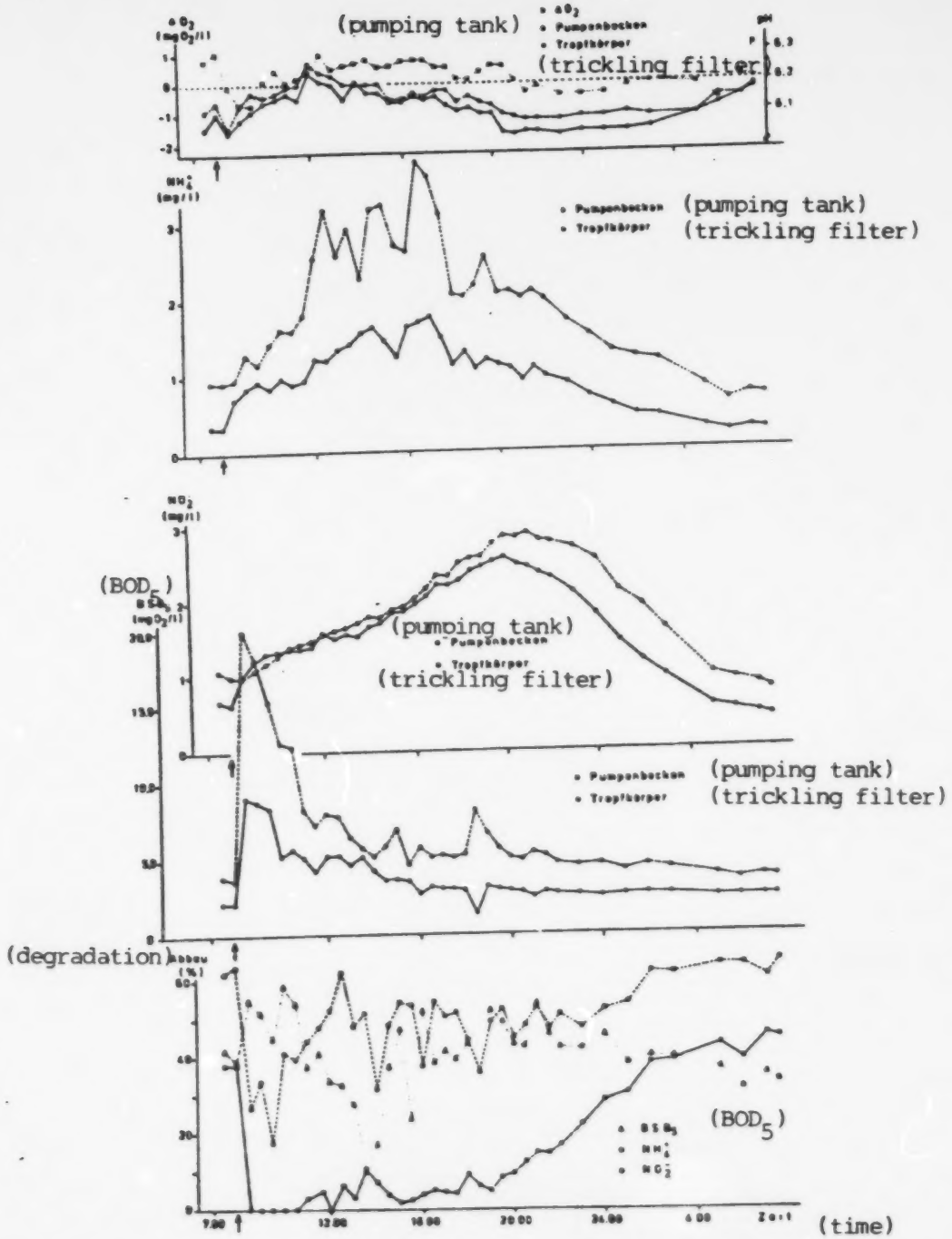

Fig. 10: Course of the diurnal curves for ammonium, nitrite, pH-value and BOD in the inflow and outflow of a relatively high-rate trickling filter as well as the relevant curves for the relative degradation efficiency. Pumping tank = inflow; trickling filter = outflow, arrows = feeding times

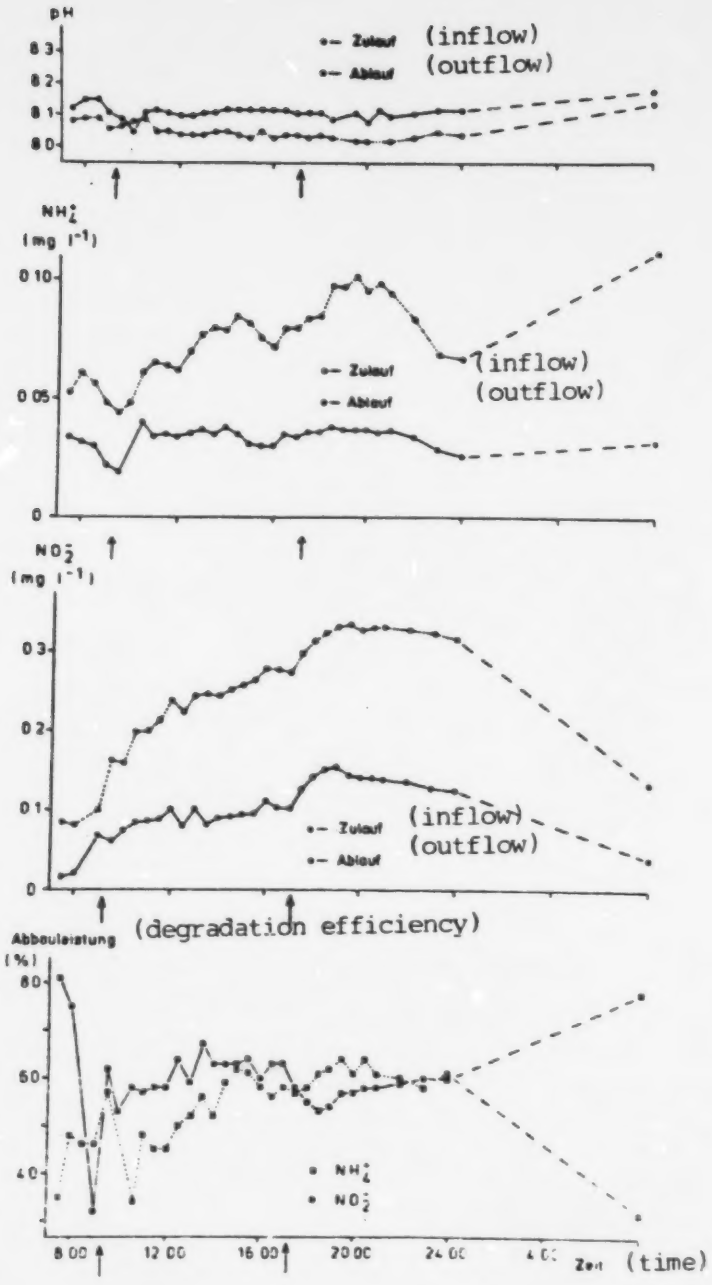

Fig. 11: Course of the diurnal curves for pH-value, ammonium and nitrite in the inflow and outflow of a relatively low-rate trickling filter integrated into a sea-water recycling system as well as the relevant curves for the relative degradation efficiency. Arrows = feeding

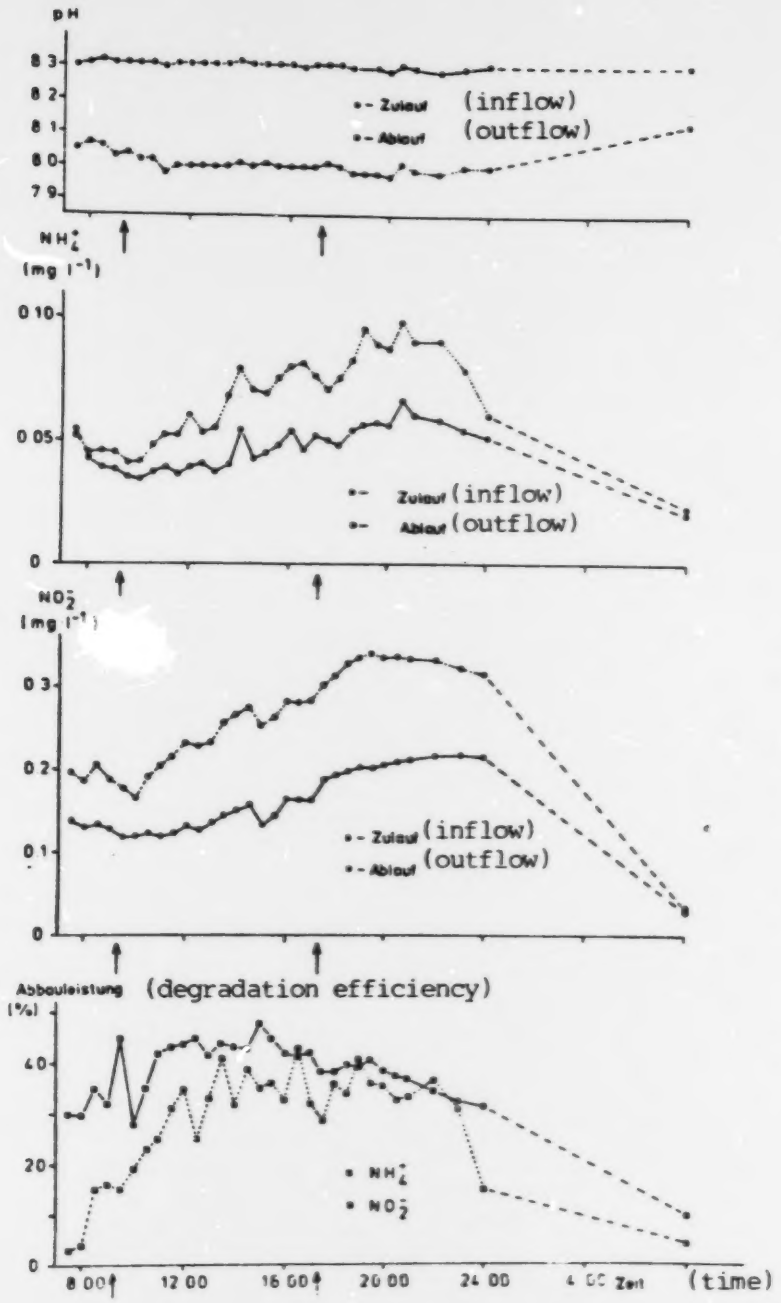

Fig. 12: Course of the diurnal curves for pH-value, ammonium and nitrite in the inflow and outflow of a relatively low-rate immersed drum reactor integrated into a sea-water recycling system as well as the relevant curves for the relative degradation efficiency. Arrows = feeding

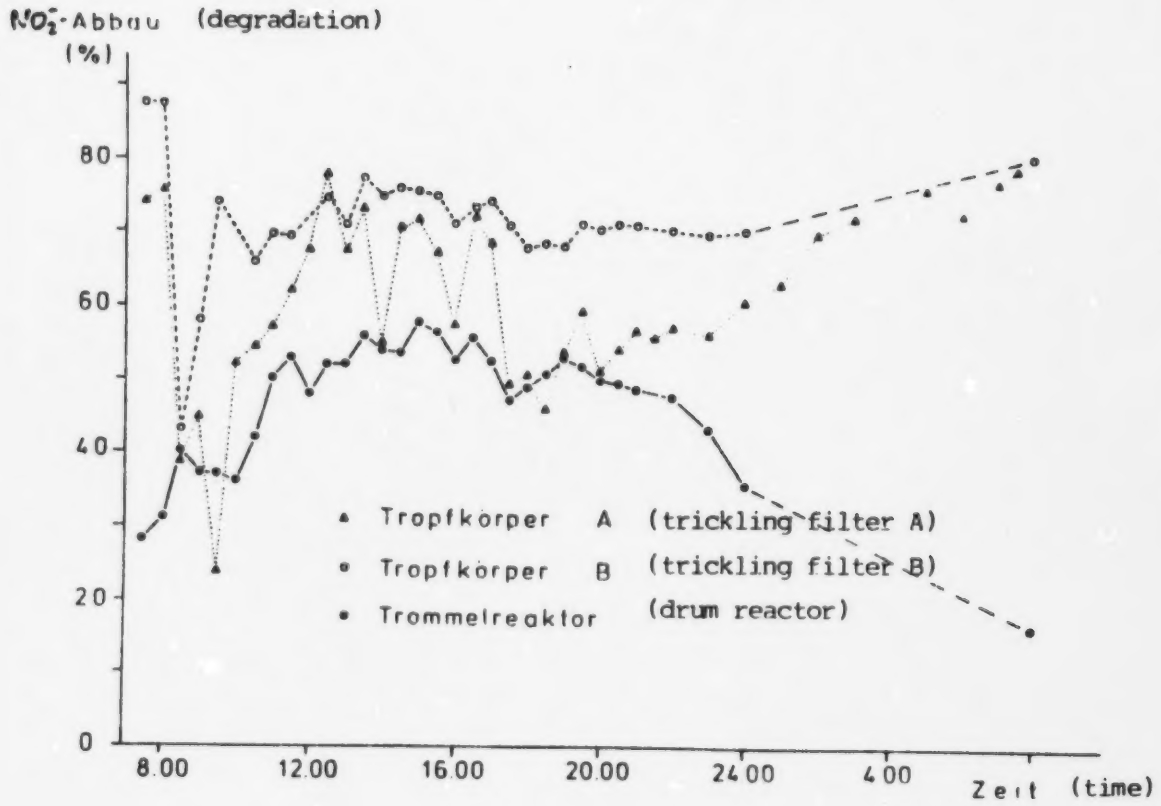

Fig. 13: Course of the daily efficiency curves for nitrite oxidation in biological filters which were connected to high-rate (trickling filter A) and low-rate recycling systems (trickling filter B and drum reactor). In this case the amounts of nitrites produced within the bio-filter by the first nitrification stage are included in the efficiency curves.

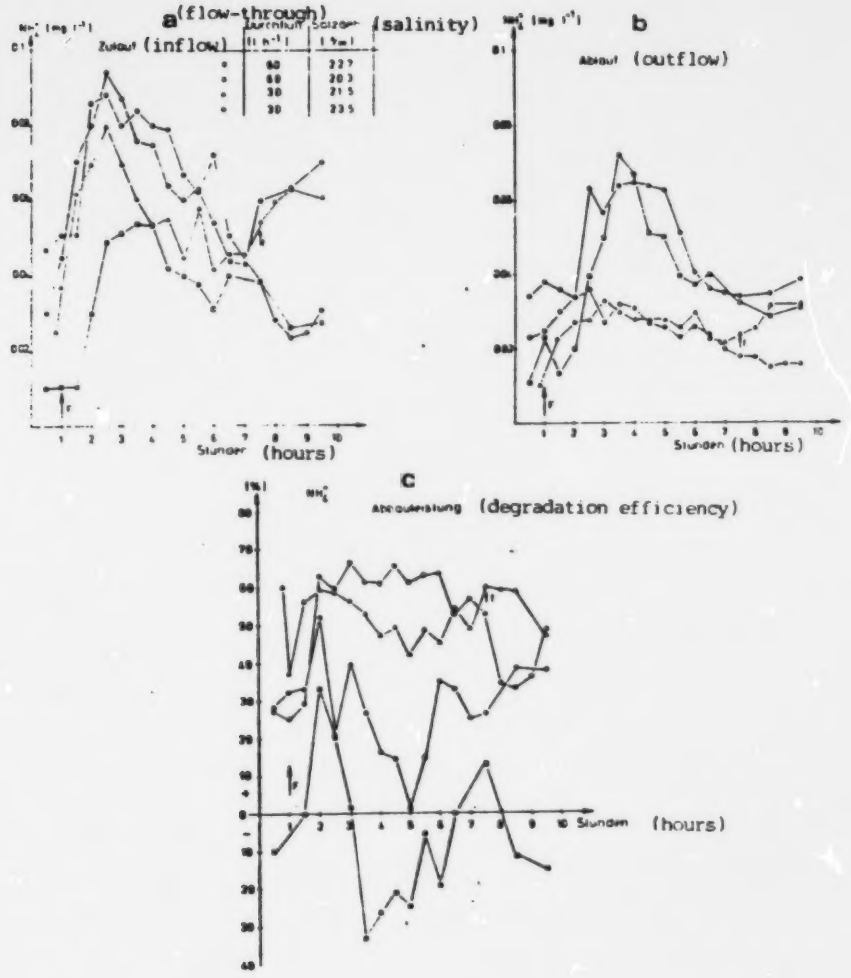

Fig. 14: Treatment of fish effluent in a brackish water recycling system. Ammonium oxidation in a rotating drum reactor under different operating conditions (constant 60 l per hour: open circles and squares; reduced flow-through (30 l/h) during the first 6 hours after feeding; filled-in circles and squares). The curves for 4 successive test days are illustrated: (a) = inflow values; (b) = outflow values; (c) = percentage degradation efficiency; F = feeding

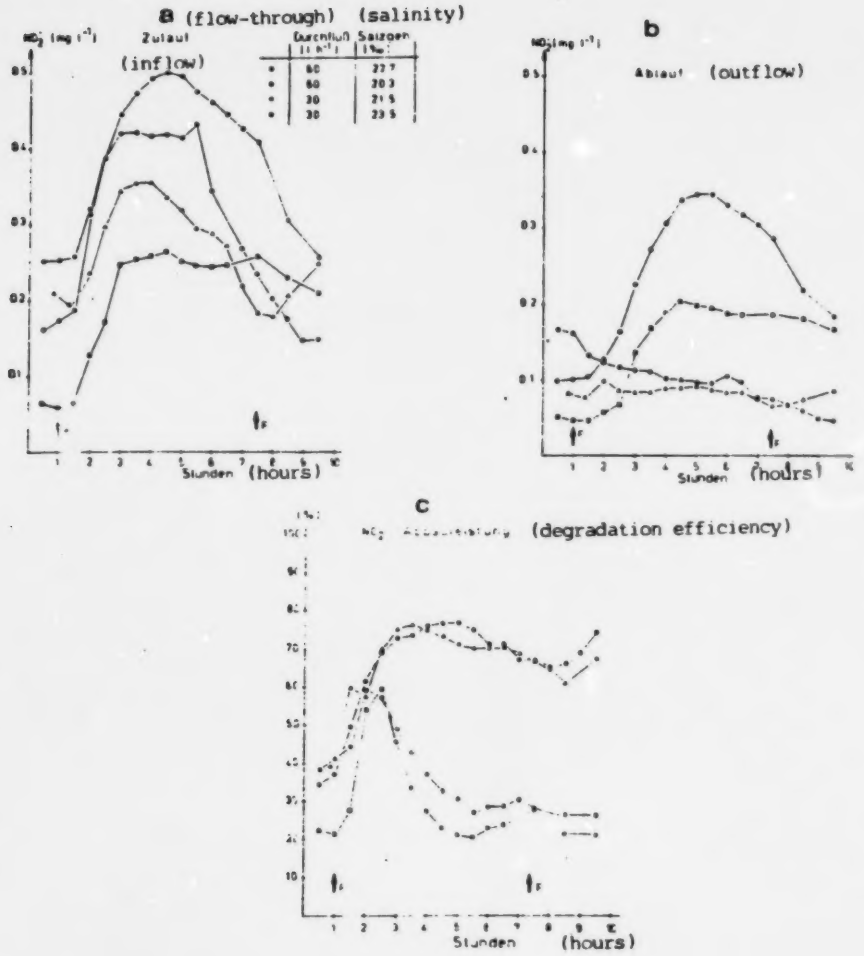

Fig. 15: Treatment of fish effluent in a brackish water recycling system. Nitrite oxidation in a rotating drum reactor under different operating conditions (constant 60 l per hour: open circles and squares; reduced flow-through (30 l/h) during the first 6 hours after feeding; filled-in circles and squares). The curves for 4 successive test days are illustrated: (a) = inflow values; (b) = outflow values; (c) = percentage degradation efficiency; F = feeding

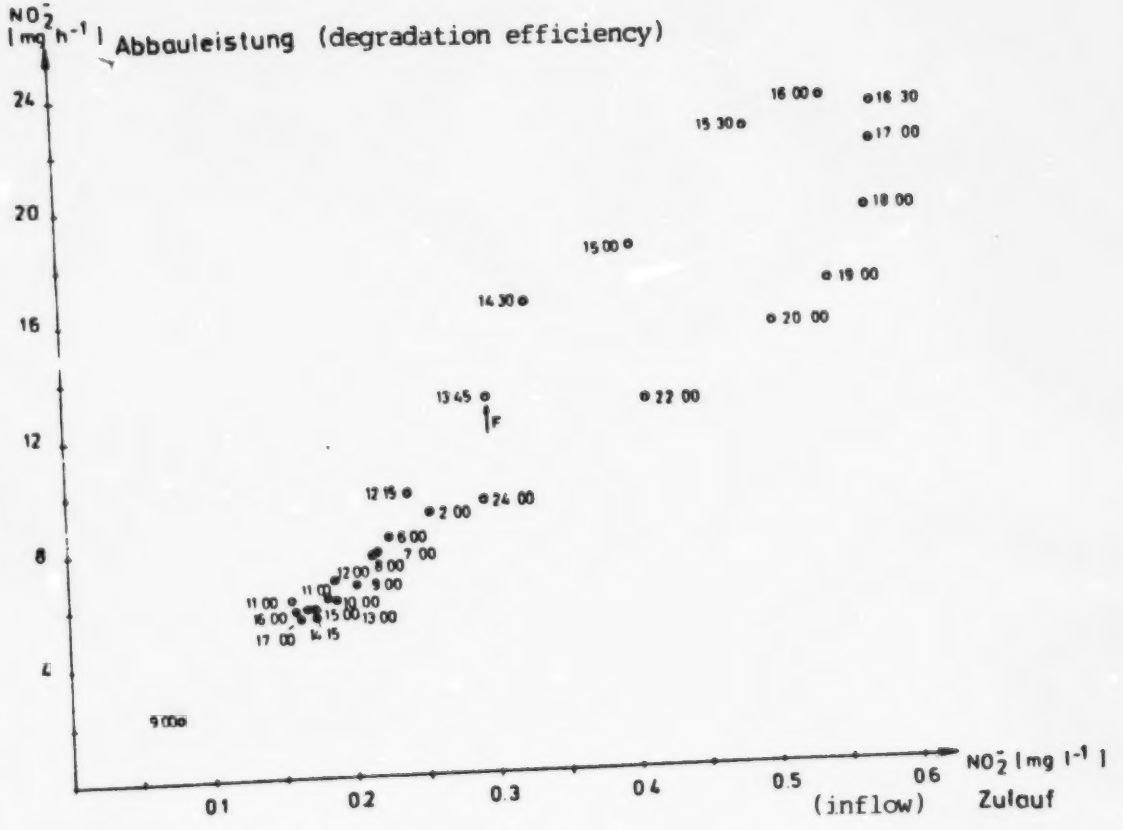

Fig. 16: Nitrification of fish effluents in a brackish recycling system. Change in the nitrite oxidation (mg/h) in a rotating drum reactor as a function of the inflow concentration on days with feeding (open circles) and without feeding (filled-in circles). F = feeding

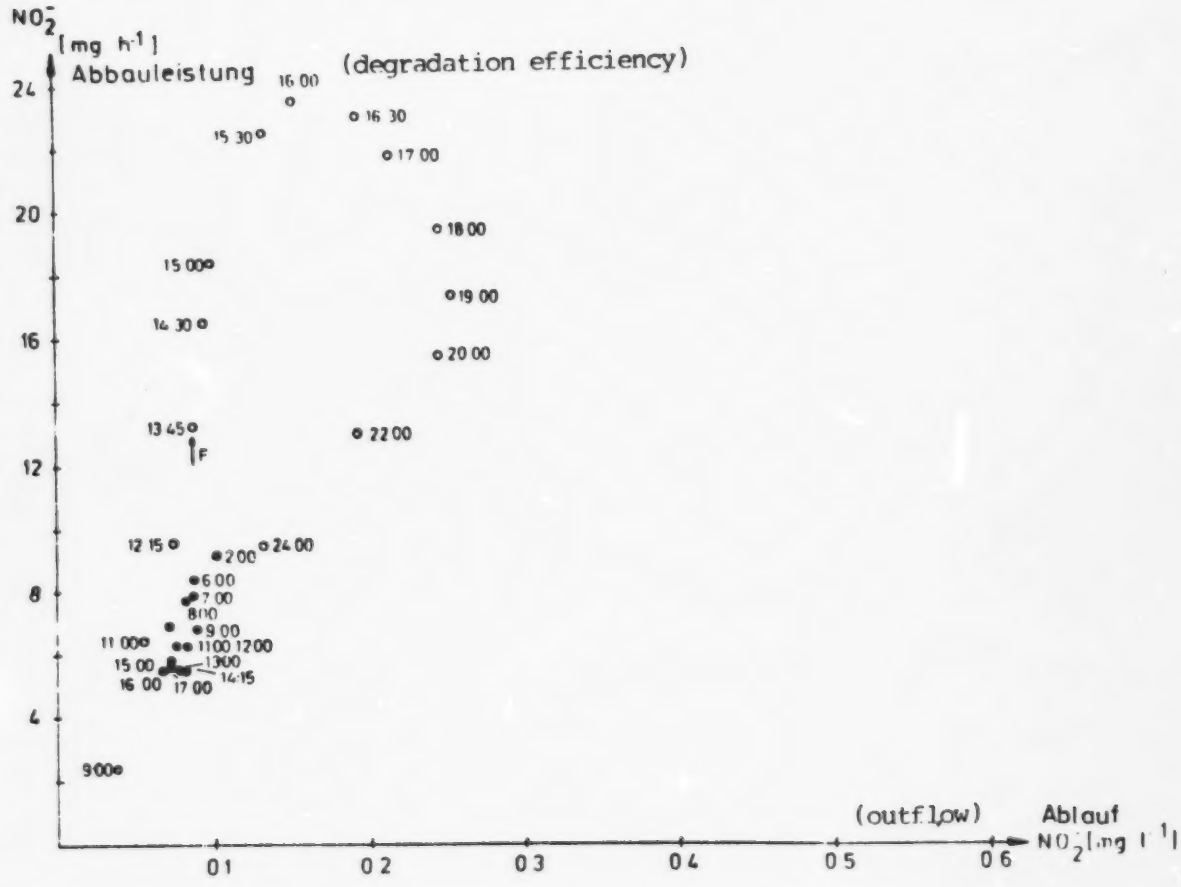

Fig. 17: Nitrification of fish effluents in a brackish recycling system. Change in the nitrite oxidation (mg/h) in a rotating drum reactor as a function of the outflow concentration on days with feeding (open circles) and without feeding (filled-in circles). F = feeding

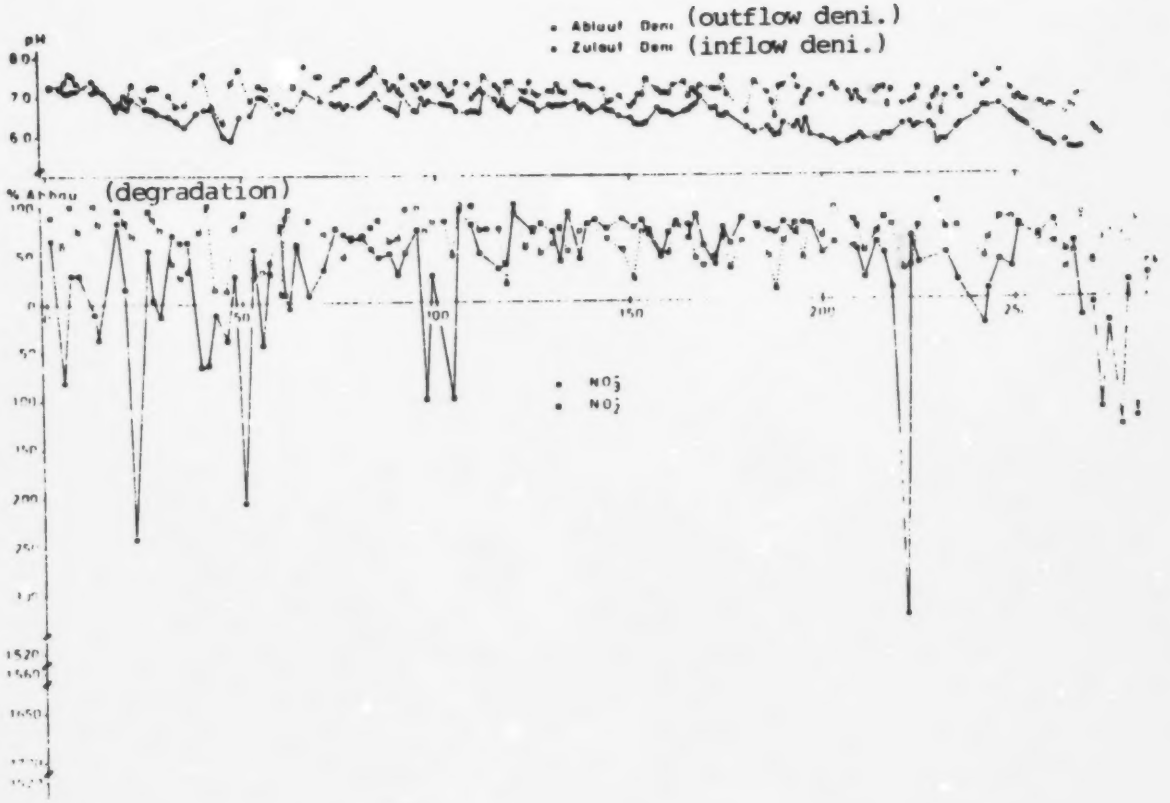

Fig. 18: Long-term observations on fluctuations in nitrate elimination in anaerobic denitrification stage operated in bypass and its effects on complete nitrate reduction. Flow-through rate = 3 - 4 l/min.; retention time about 6 h; temperature = 24 - 26°C; salinity = 16 °/00 S; oxygen content = 0 - 0.5 mg/l; sampling = 8:00 a.m.; top curves = pH-values in inflow and outflow of the denitrification stage; bottom curves = percentage degradation of nitrate and nitrite.

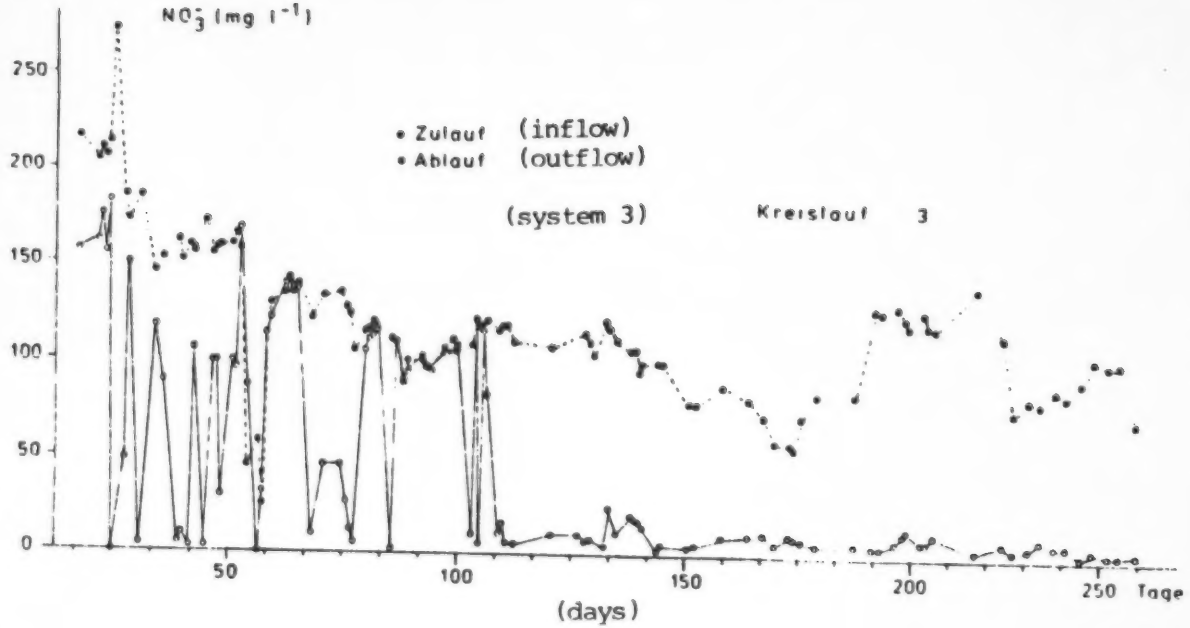

Fig. 19: Run-in phase and stable operating phase of an anaerobic denitrification stage. The inflow and and outflow values are illustrated (sampling 8:00 a.m.; temperature: 21 - 23°C; salinity: 16 $^0/_{00}$ S).

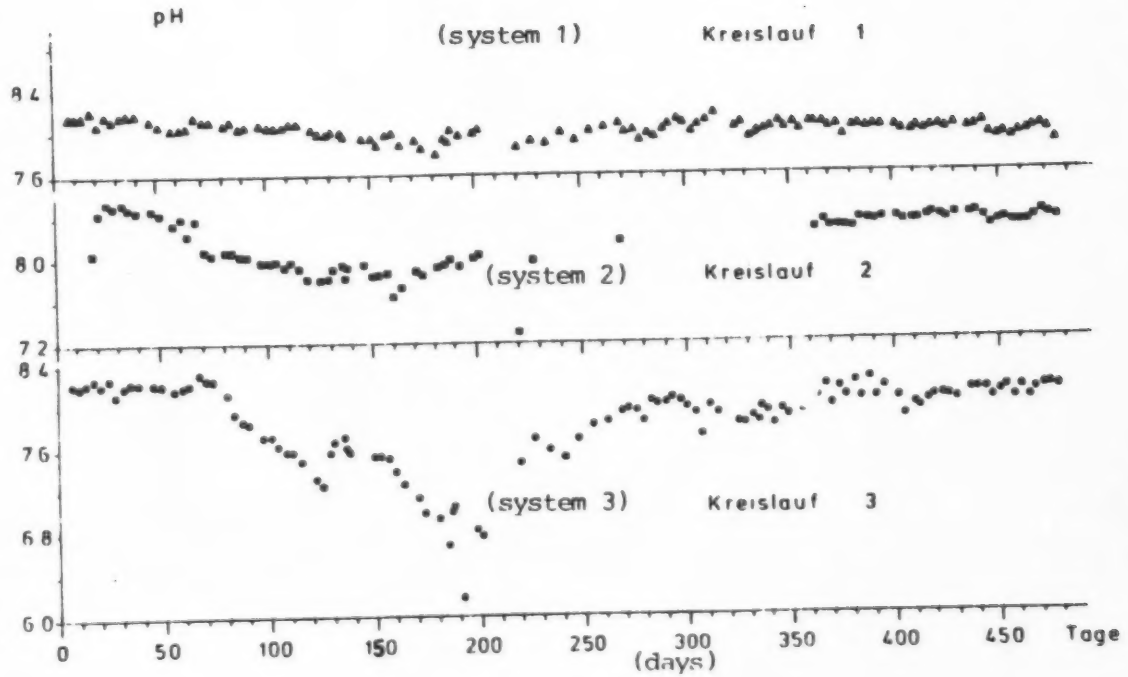

Fig. 20: Effect of the integration of an anaerobic denitrification stage on the pH-stabilization of a brackish water recycling system (recycling system 3: connection of the denitrification on test day 110; beginning of the stable operating phase on test day 200).

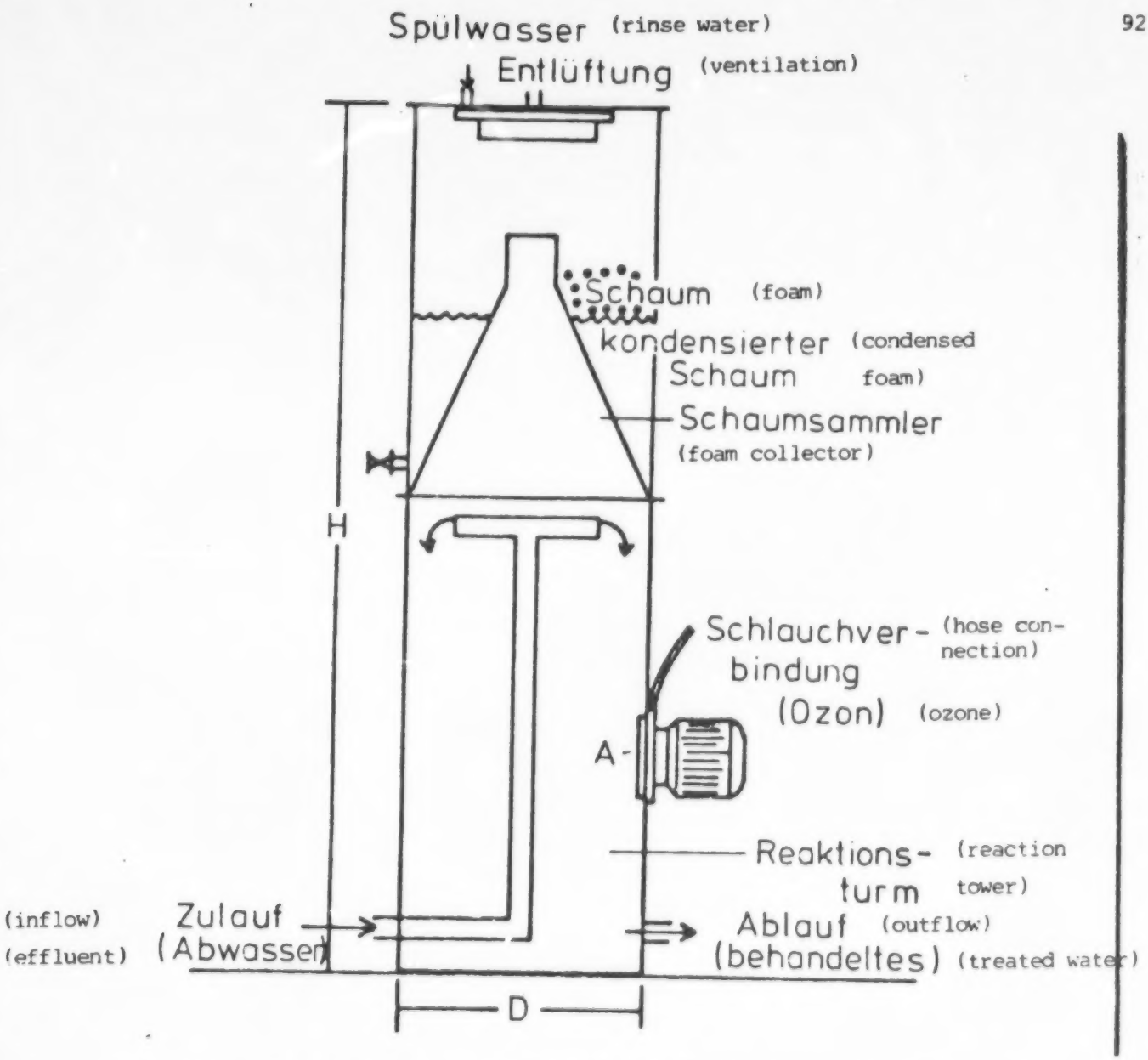

Fig. 21: Cross-section of a contact tower for ozone treatment. Total volume = 360 l; A = dispergator (2,400 rpm); H = height of the tower (2.80 m), D = total diameter (60 cm).

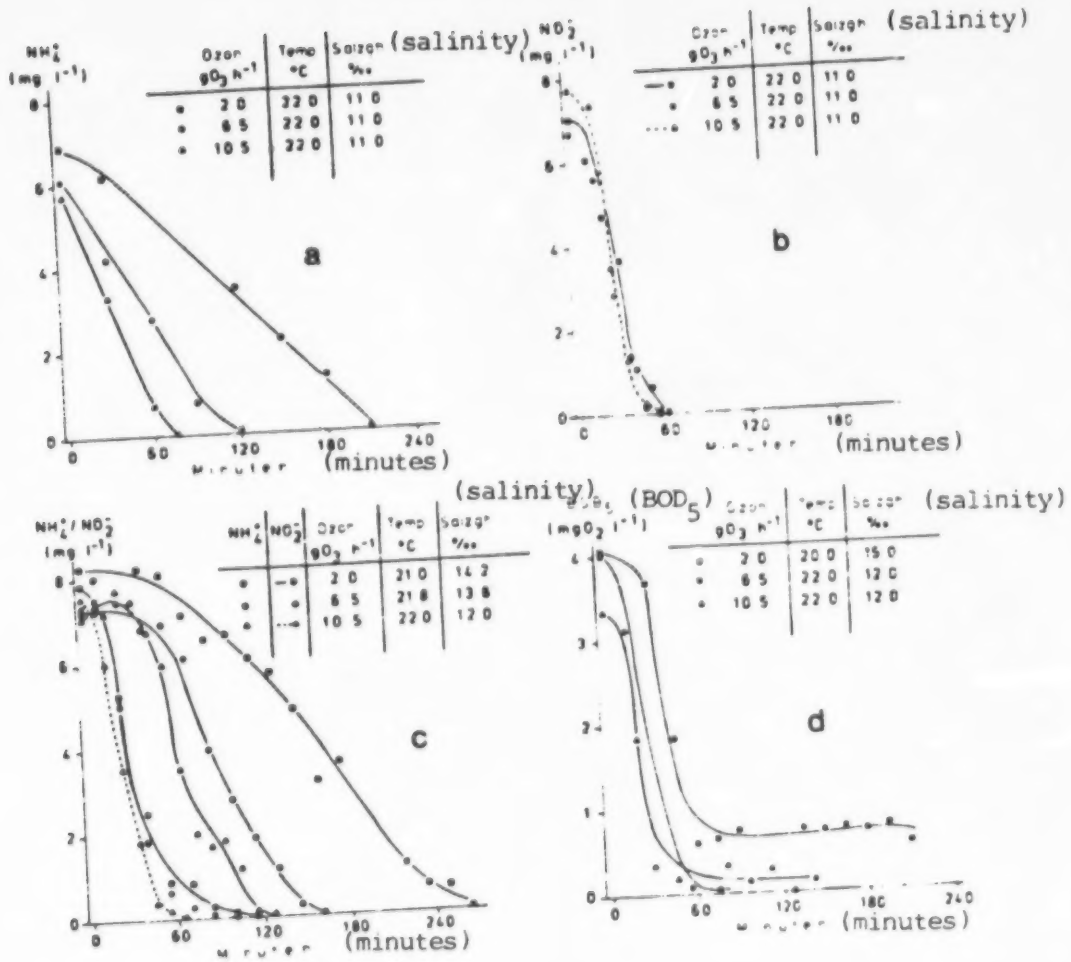

Fig. 22: Course of the oxidation curves for ammonium, nitrite and BOD at a flow-through rate of 0.5 m^3/h (retention time: 40 min.) in the contact tower of the bypass ozonization and three different ozone concentrations.(a) ammonium,(b) nitrite,(c) ammonium and nitrite together in a medium to be treated,(d) BOD.

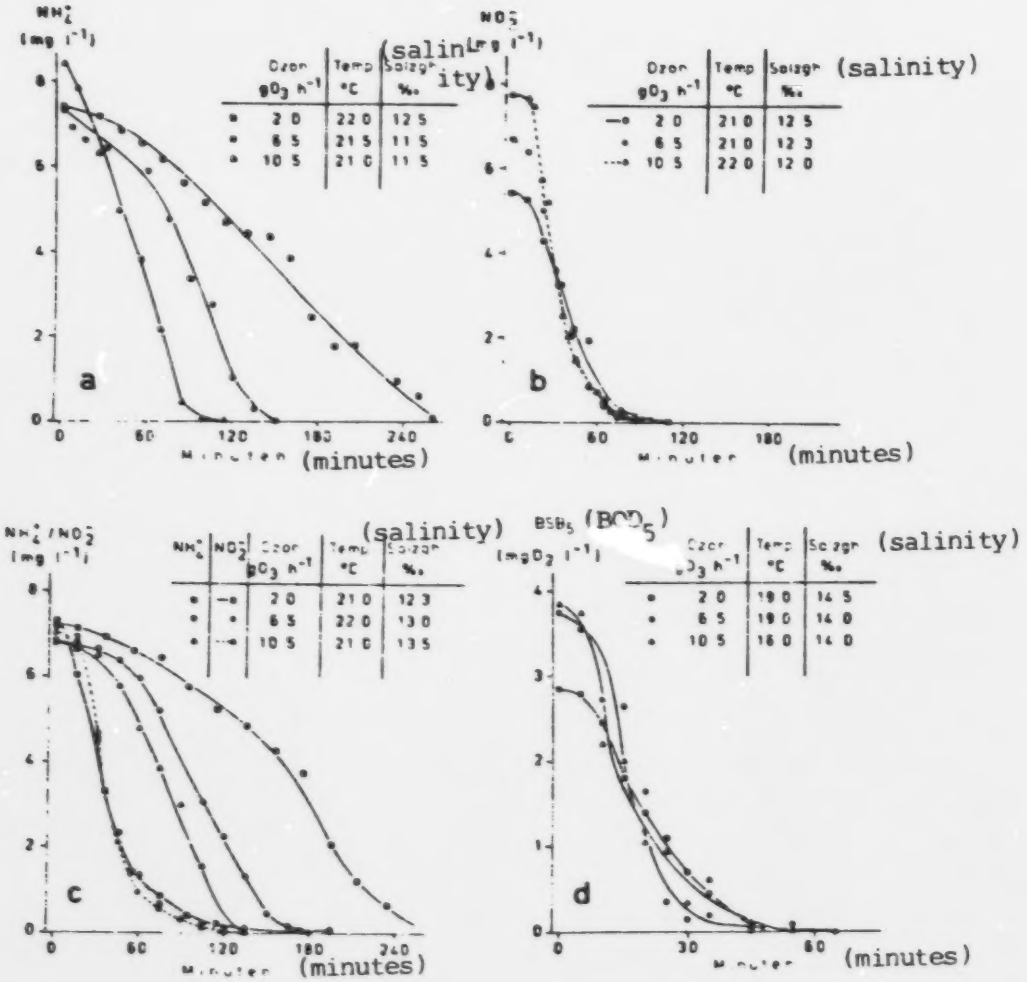

Fig. 23: Course of the oxidation curves for ammonium, nitrite and BOD at a flow-through rate of 1.0 m^3/h (retention time: 20 min.) in the contact tower of the bypass ozonization and three different ozone concentrations.(a) ammonium,(b) nitrite,(c) ammonium and nitrite together in a medium to be treated,(d) BOD.

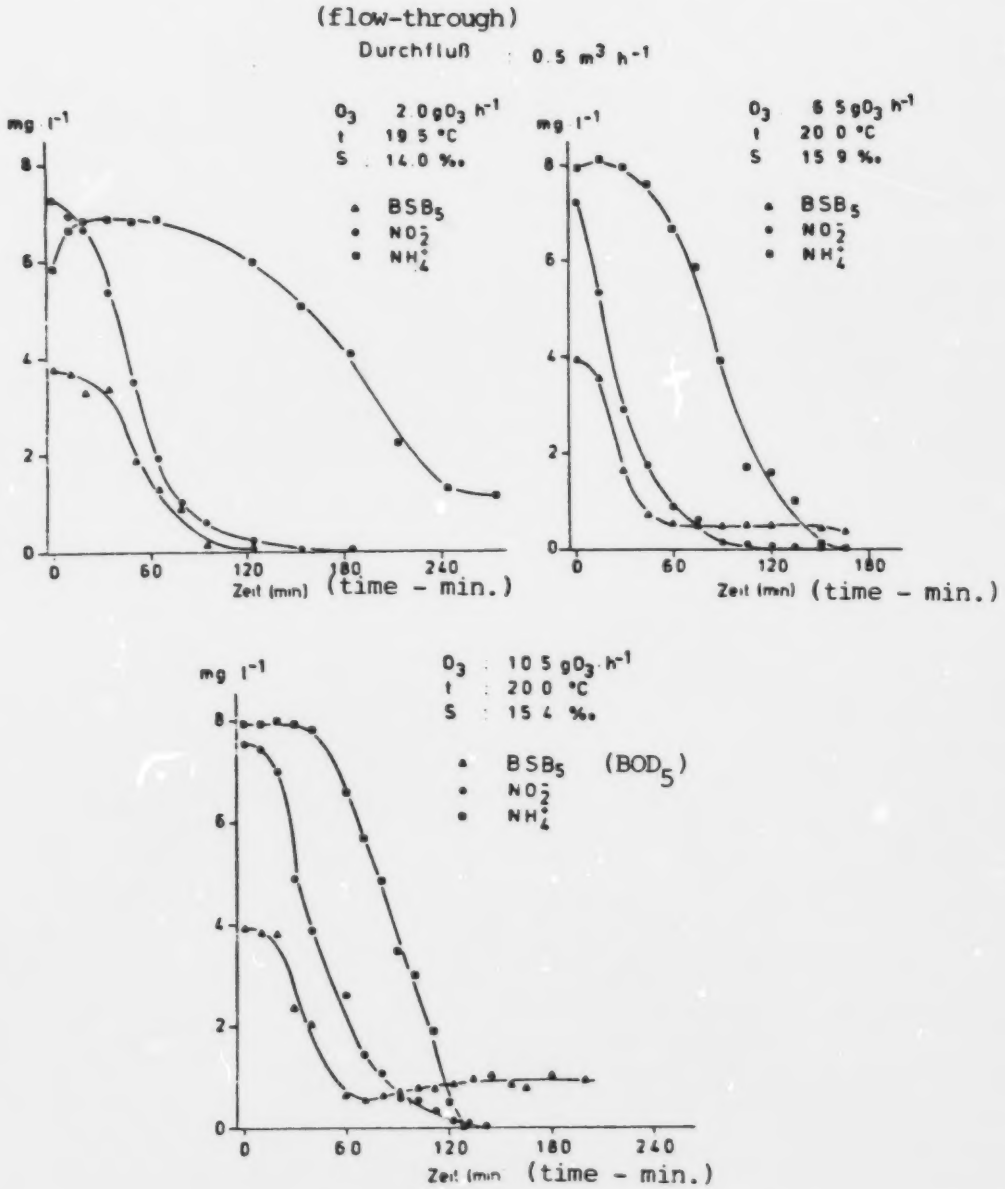

Fig. 24: Simultaneous oxidation of ammonium, nitrite and BOD as a function of the ozone used per time unit. Flow-through rate: 0.5 m^3/h, retention time about 40 minutes.

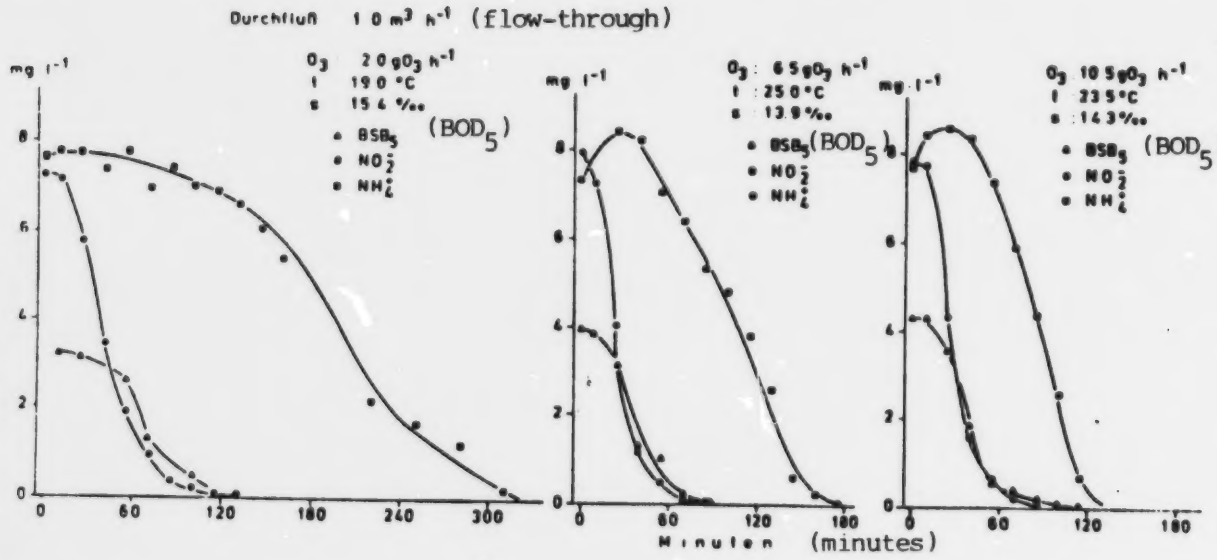

Fig. 25: Simultaneous oxidation of ammonium, nitrite and BOD as a function of the ozone used per time unit. Flow-through rate 1.0 m^3/h, retention time about: 20 minutes.

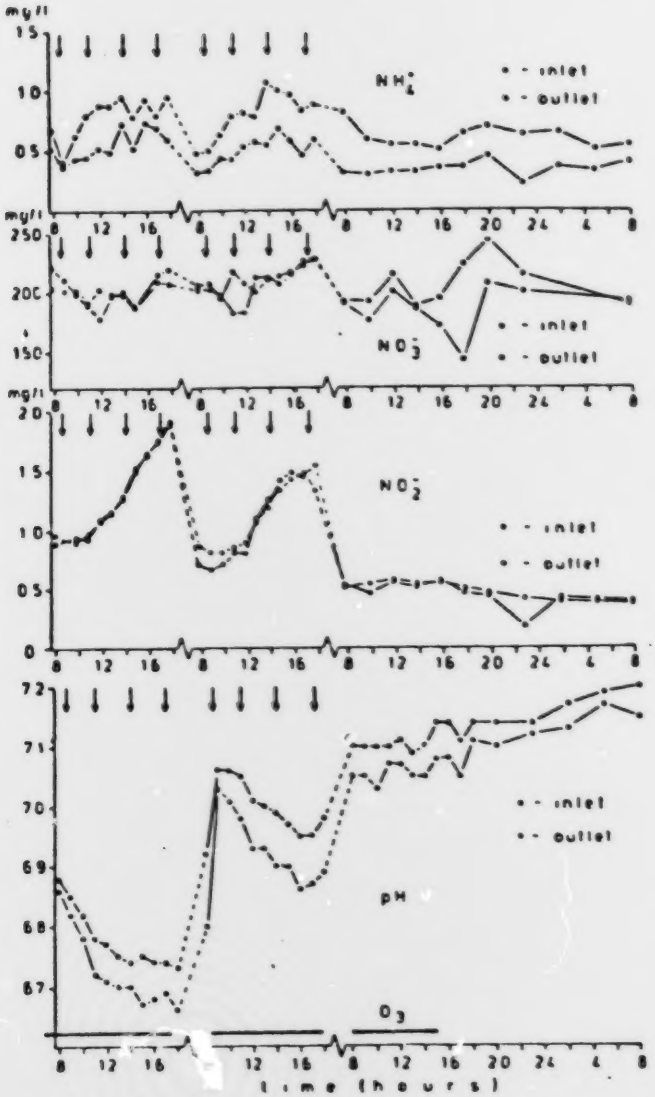

Fig. 26: Variations in the nitrogen components and pH-values in the inflow and outflow of a circular flow tank as a function of feeding. Fish stock: Tilapia; density 0.09 kg/l; mean fish weight 52 g; water flow through 11 - 12 l/min. Arrows indicate feeding times; daily ration 2% of body weight per day; O_3 (bars) = times ozone used.

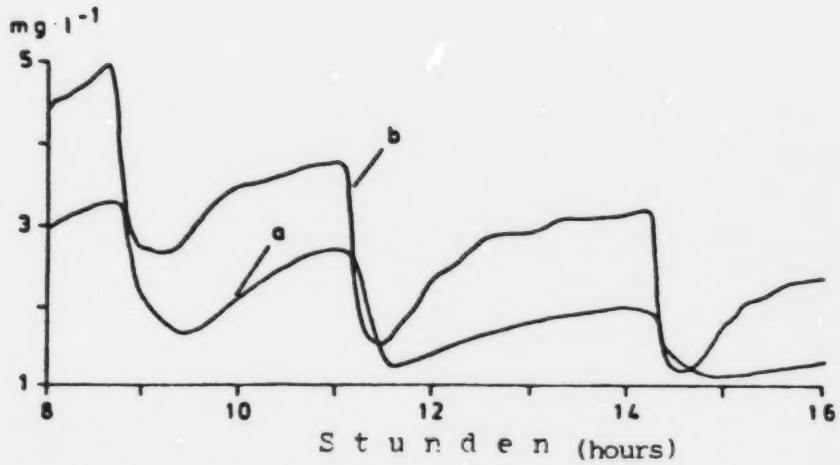

Fig. 27: Course of the oxygen curves in the outflow of 2 identically operated fish tanks as a function of feeding. Stocking density 0.09 kg/l; mean fish weight 52 g; oxygen content in the inflow water 11 - 12 mg/l; water exchange approximately every 30 minutes; a = tank 1; b = tank 2

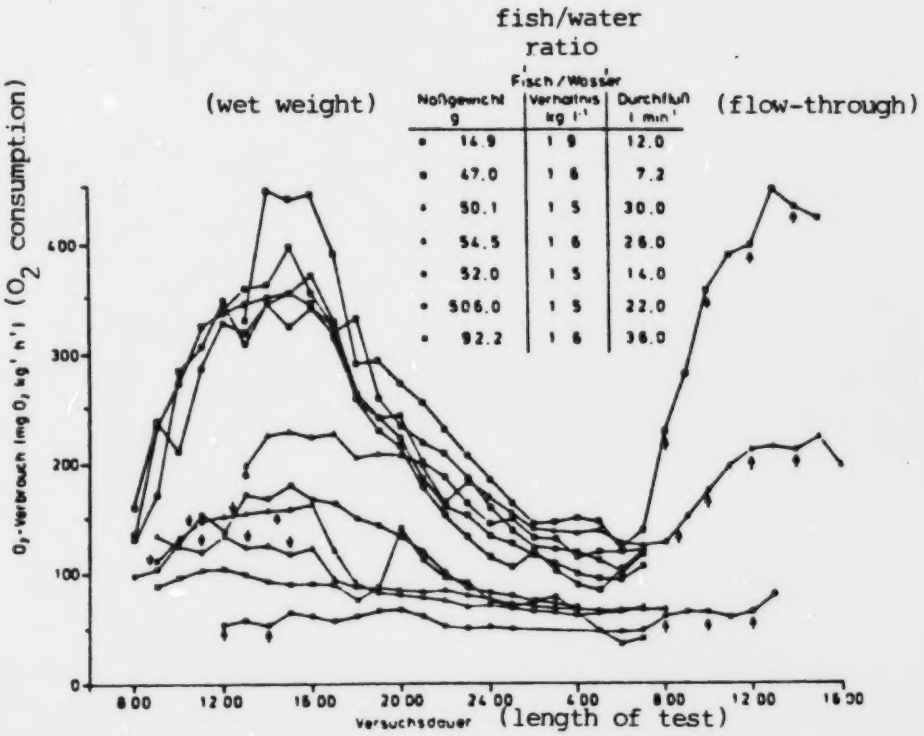

Fig. 28: Oxygen consumption of Tilapia as a function of stocking density, individual size, water exchange and time of day. Arrows indicate feeding times.

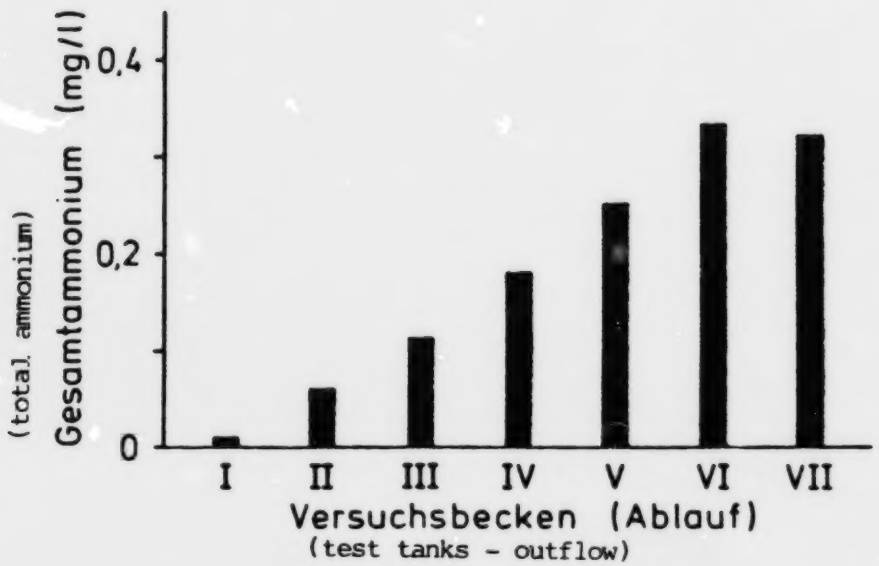

Fig. 29: Tests on the progressive exposure of trout to metabolic excretion products from fish rearing. Mean diurnal concentration for total ammonium in the outflow of 7 sequentially connected test tanks with the same stocking densities.

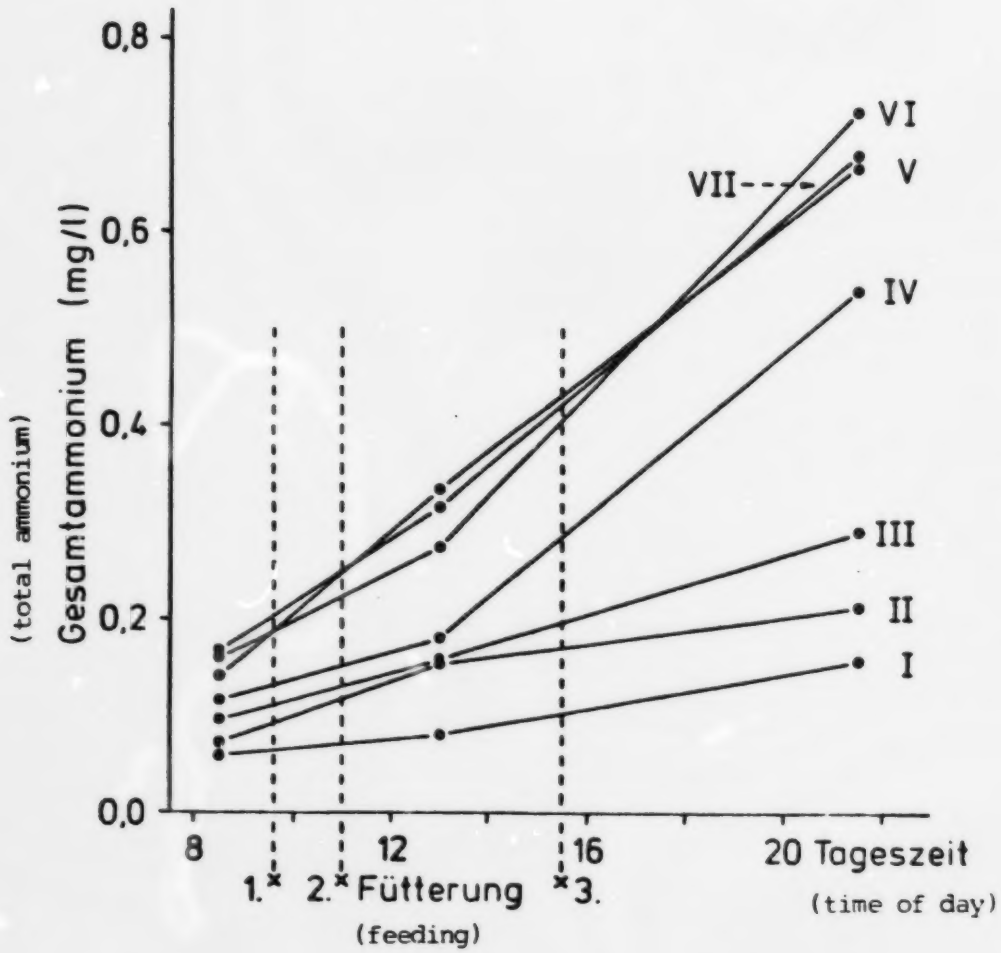

Fig. 30: Tests on the progressive exposure of trout to metabolic excretion products from fish rearing. Diurnal course of curves for total ammonium in the outflow of 7 sequentially connected test tanks (I - VII) with the same stocking densities and with three feedings a day.

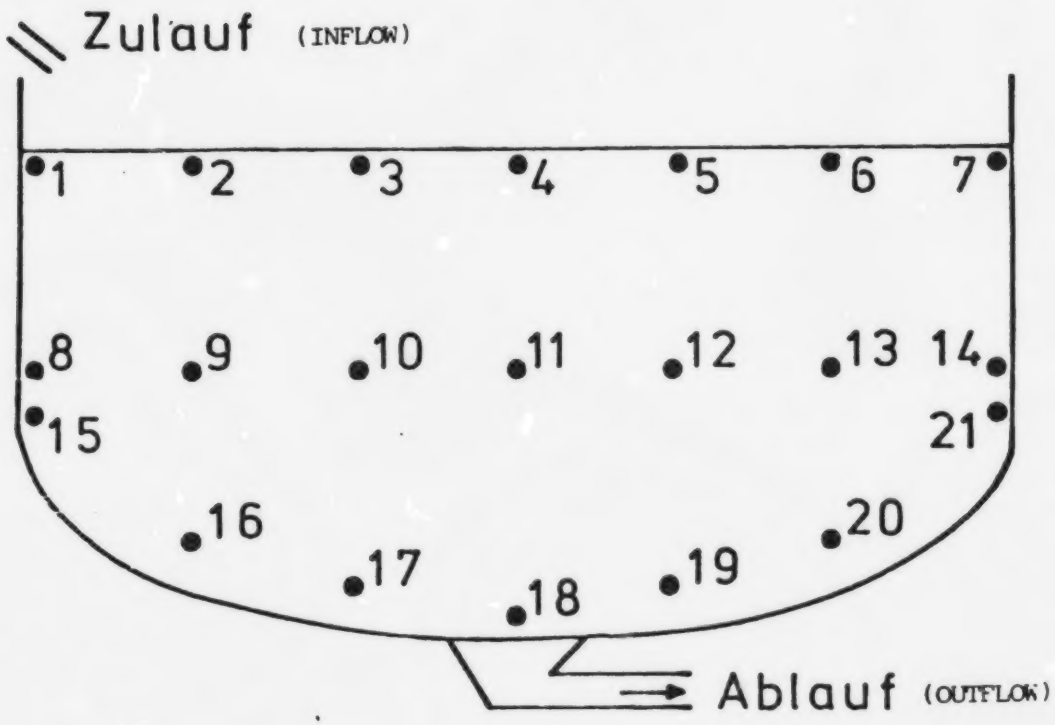

Fig. 31: Position and numbering of the sampling points in tank 1 (Auetal May 26 - 27, 1982)

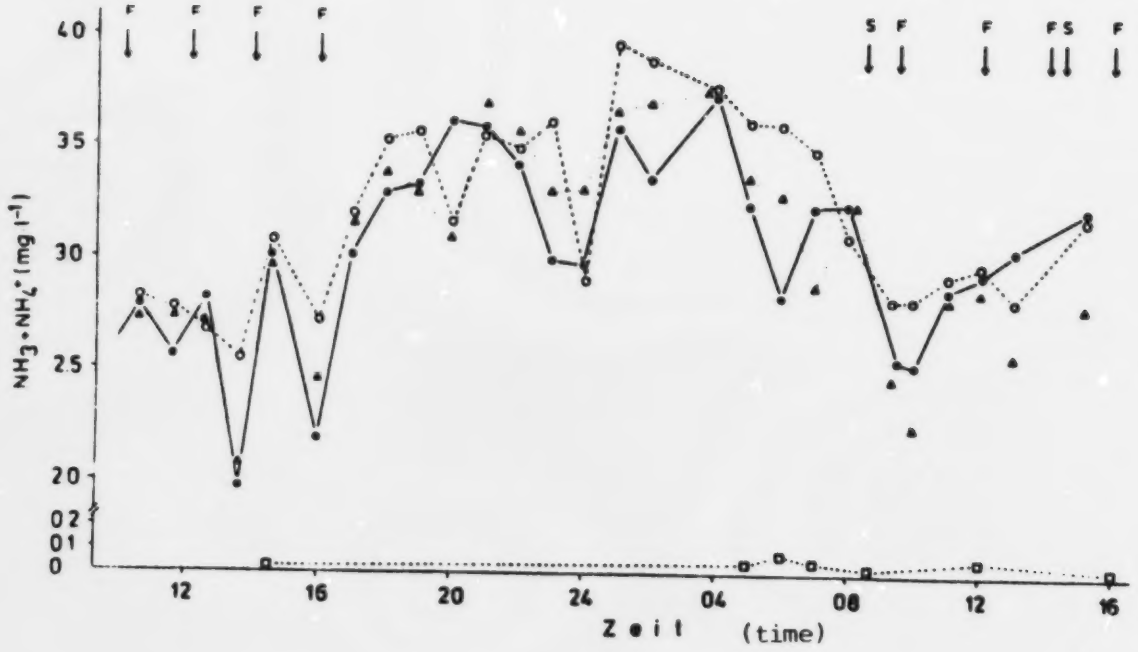

Fig. 32: Auetal Fish Culture Facility, Tank 1. Daily cycle of ammonium contents in the inflow (□ - - - - □), outflow (●——————●) and at positions 5 and 19 (see Fig. 31 for plan of positions). Positions 5 (○ - - - - ○), Position 19 (▲ . . . . . ▲).

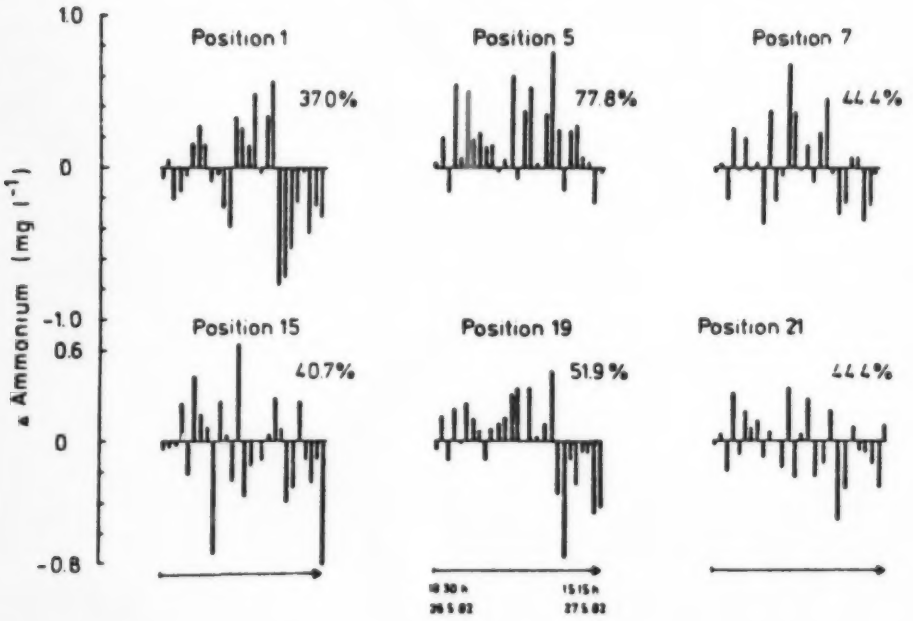

Fig. 33: Auetal Fish Culture Facility. Difference in the ammonium values at 6 observation points in tank 1 compared to the outflow values. See Figure 31 for the layout of the sampling points. n = 27. The relative frequency of high ammonium concentrations in the fish tank is given in percentage.

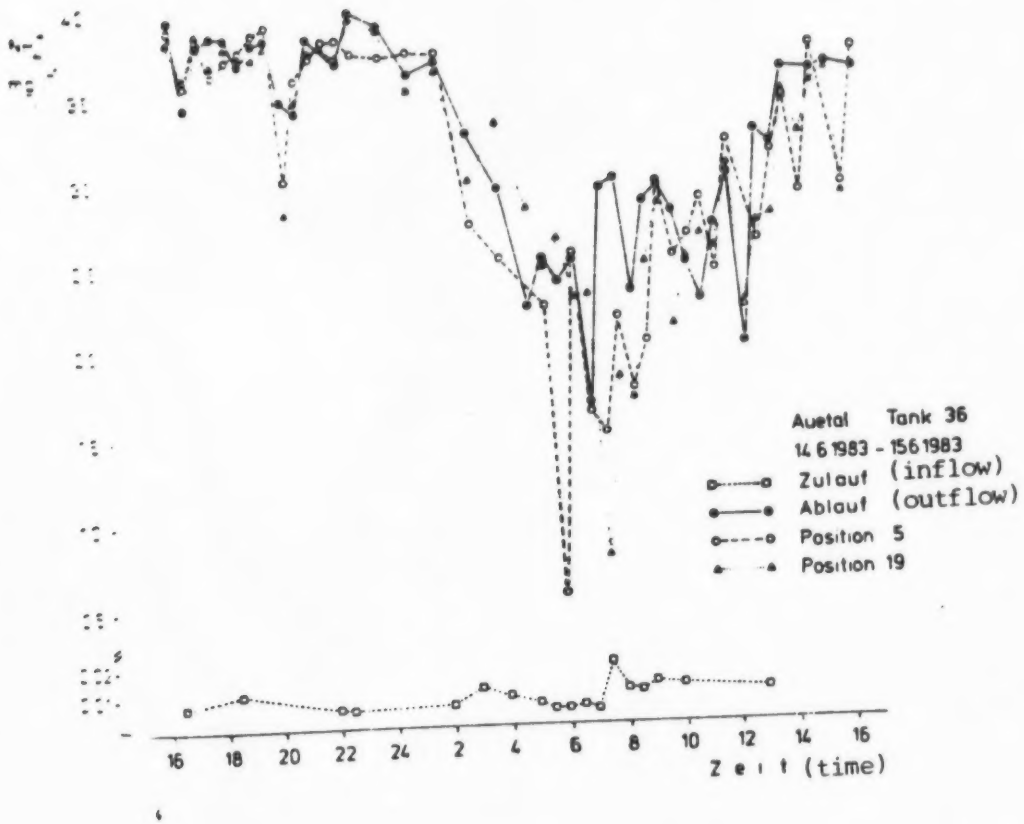
Auetal Tank 36
14 6 1983 - 15 6 1983
Zulauf (inflow)
Ablauf (outflow)
Position 5
Position 19
16 18 20 22 24 2 4 6 8 10 12 14 16
Zeit (time)

Fig. 34: Course of the daily cycle of the ammonium curves (total ammonium $NH_3 + NH_4^+$) in the inflow and outflow of Tank 36 of the Auetal system as well as within the tank.

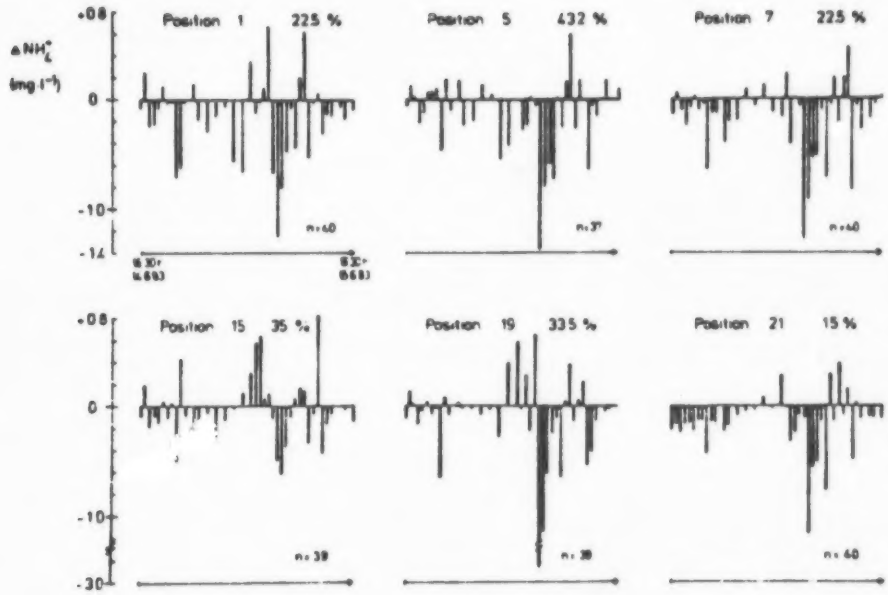

Fig. 35: Deviation of the ammonium concentration (NH_4^+ in mg/l) from the outflow value measured at six different observation points of a tank in the Auetal system.

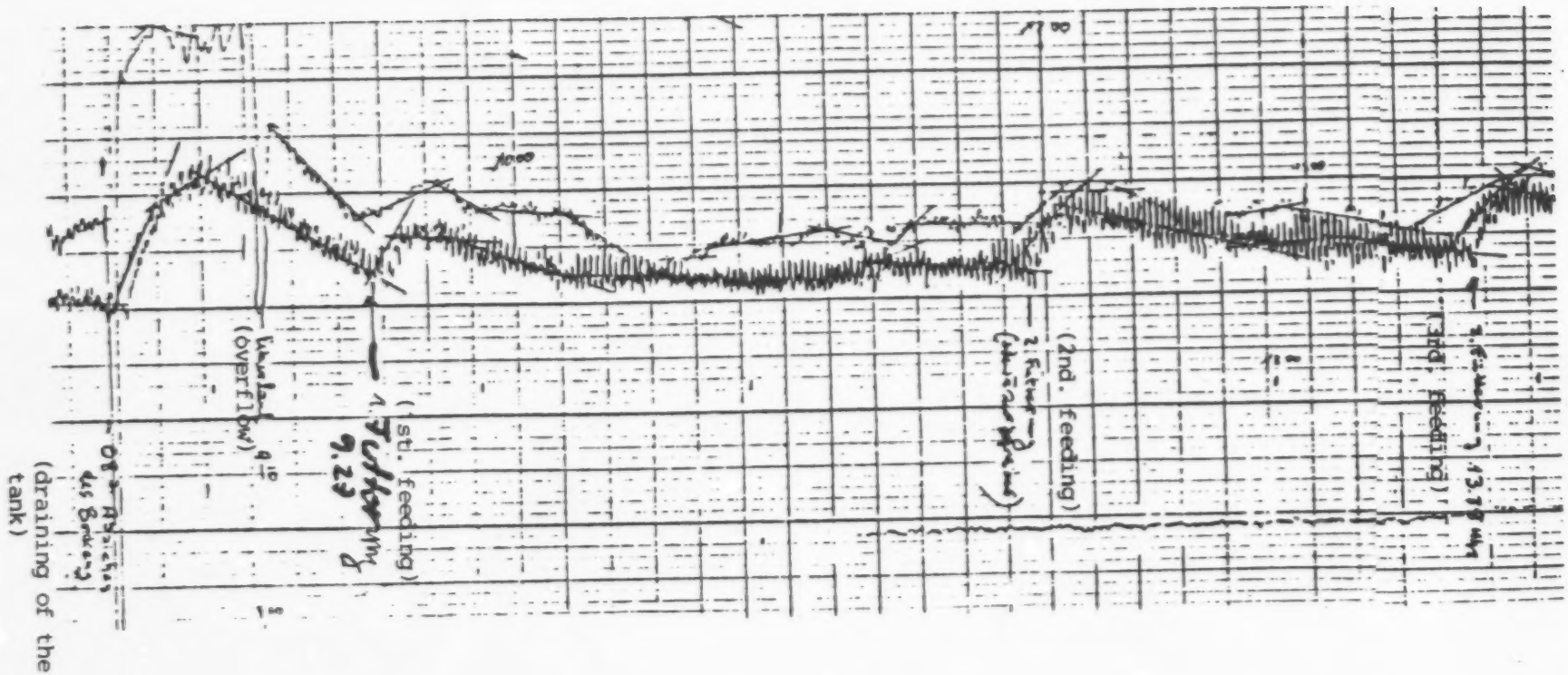

Fig. 36: Example of the recorder tracing of the oxygen content in Tank 1. The decline in O_2-content can be seen clearly from he draining-off of the bottom sludge. Even 40 minutes after the draining-off (feeding begun at 9:27 a.m.), the initial values had still not been re-established.

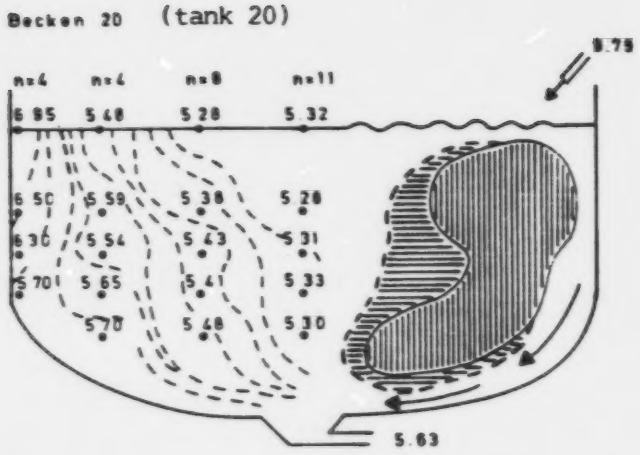

Fig. 37a: Oxygen content in mg O_2/l at 19 observation points as well as in the inflow and outflow. n = number of recordings; shaded area = preferred distribution of the fish (cross-section) as observed during the test phase

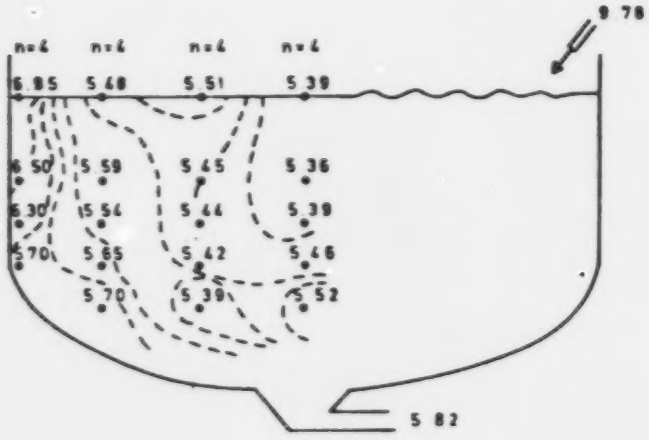

Fig. 37b: Distribution of the oxygen content in Tank 20 illustrated on the basis of 4 samples taken simultaneously.

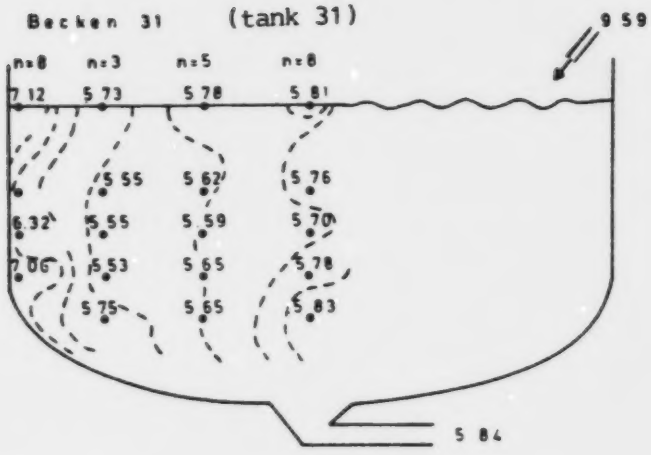

Fig. 38a: Distribution of the oxygen content in Tank 31 as well as in the inflow and outflow. Amounts in mg O_2/l; n = number of recordings.

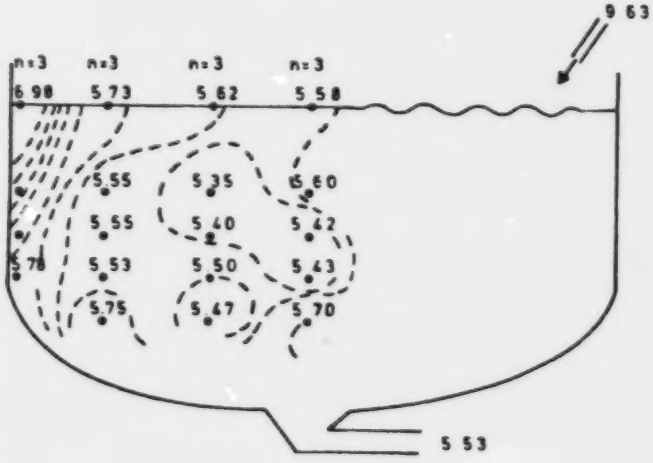

Fig. 38b: Mean oxygen concentration illustrated on the basis of three samples taken simultaneously between 4:00 p.m. and 6:00 p.m.

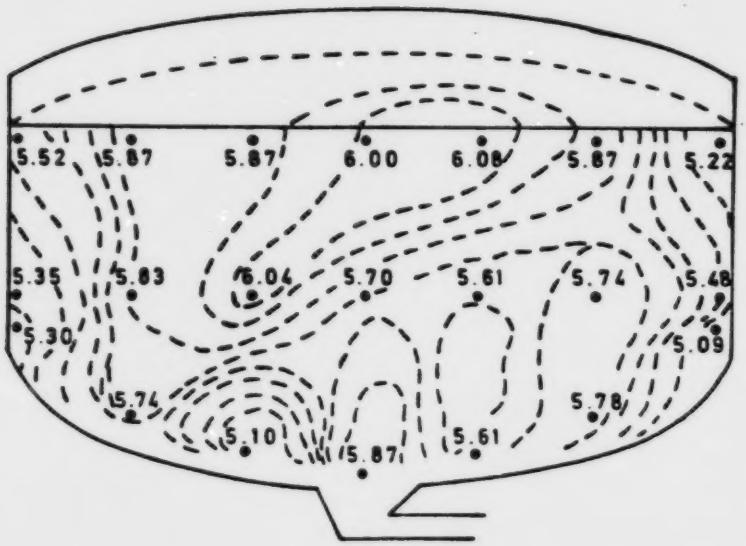

Fig. 39: Auetal Fish Culture Facility, Tank 1. Cumulative extinction values (for rhodamine B) during the dilution phase of about 12 hours recorded on the basis of 23 half-hour samples taken simultaneously at 21 observation points. Isolines = distribution of water bodies at different retention times.

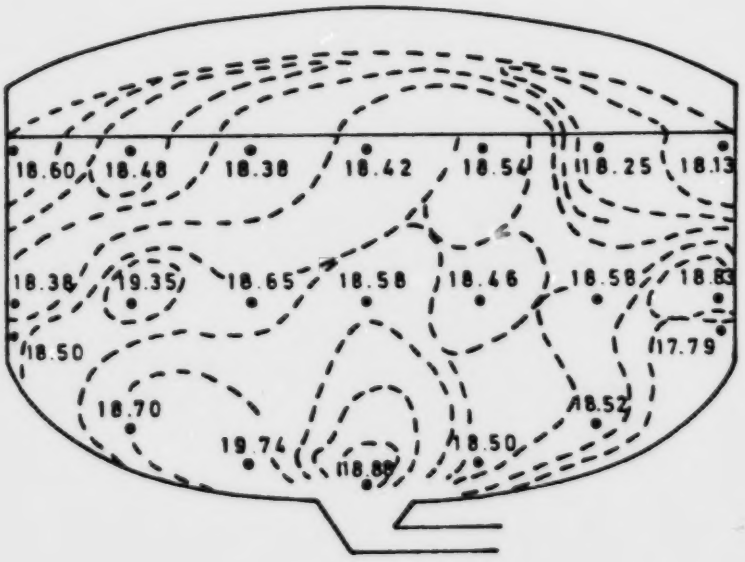

Fig. 40: Auetal Fish Culture Facility, Tank 1. Mean relative dye concentration (extinction values for rhodamine B) with continuous addition (12 h), n = 24.

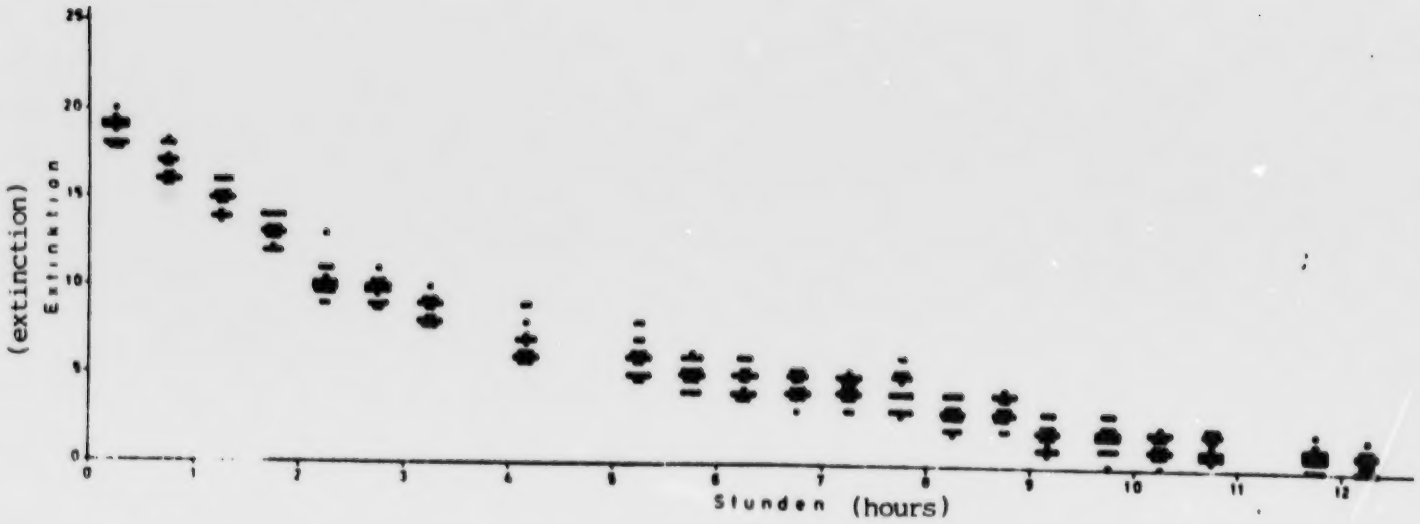

Fig. 41: Auetal Fish Culture Facility, Tank 1. Decrease in extinction values during the dilution phase as measurement of the actual water exchange rate. X-axis: time in hours after the adding of rhodamine had been stopped. The values for 21 samples taken simultaneously are illustrated (see Fig. 31).

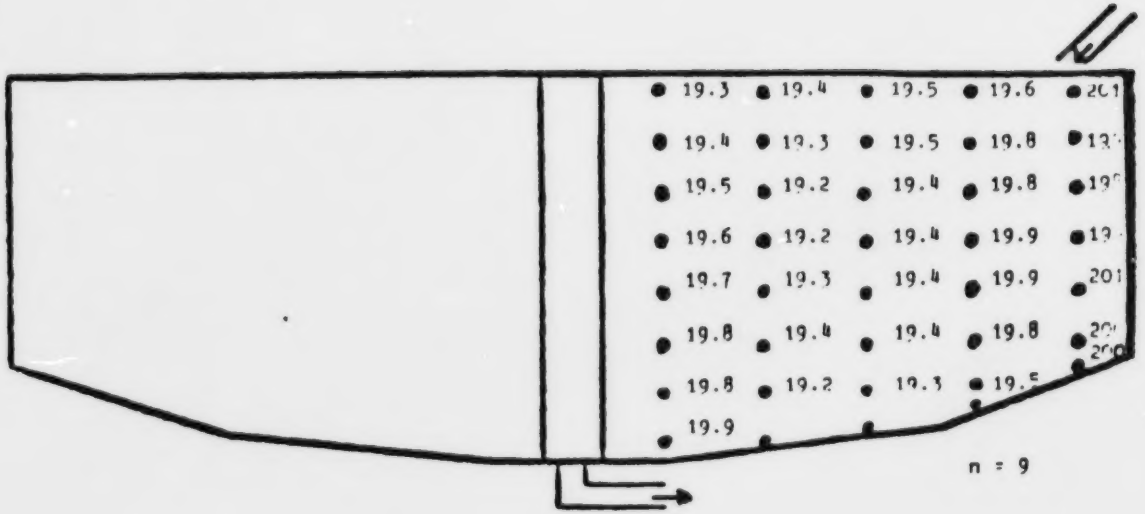

Fig. 42: Distribution of the mean oxygen concentration (mg/l) in Tank 3D based on 9 samples taken at approximately hourly intervals at 36 observation points.

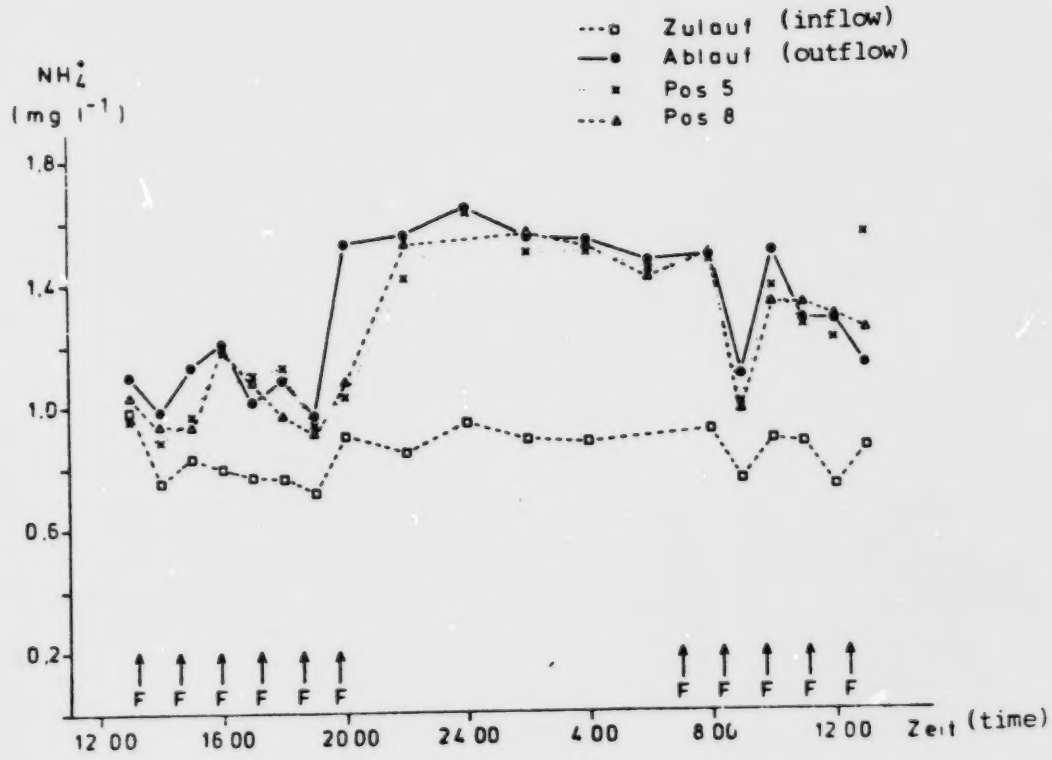

Fig. 43: Course of the daily cycle of ammonium curves for the inflow and outflow of Tank D2 of the Kellinghusen system as well as inside the tank (two positions). F = feeding.

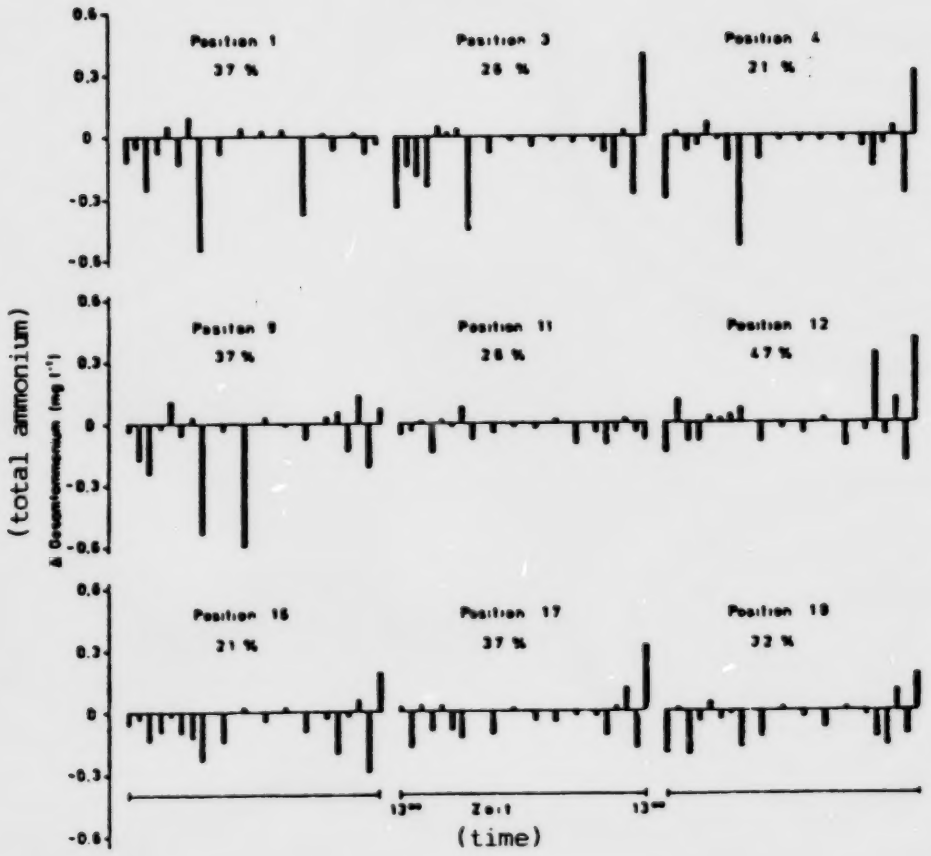

Fig. 44: Deviation of the ammonium concentration (NH_4^+ in mg/l) from the outflow value measured at nine different observation points of a tank in the Kellinghusen system.